United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-236**

Managing Piñon-Juniper Ecosystems for Sustainability and Social Needs

April 26-30, 1993
Sante Fe, New Mexico

Aldon, Earl F.; Shaw, Douglas W., technical coordinators. 1993. Managing Piñon-Juniper Ecosystems for Sustainability and Social Needs; proceedings of the symposium 1993 April 26-30; Sante Fe, New Mexico. Gen. Tech. Rep. RM-236. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 169 p.

Abstract

The purpose of this symposium was to assist the USDA Forest Service, other federal land management agencies, and the New Mexico State Land Office in the future development and management of the piñon-juniper ecosystem in the Southwest. Authors assessed the current state of knowledge about the piñon-juniper resource and helped develop future research and management goals.

USDA Forest Service
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October 1993

Managing Piñon-Juniper Ecosystems for Sustainability and Social Needs

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Welcome and Opening Remarks

Jose Salinas[1] and Bob Langsenkamp[2]

Jose Salinas...

Good afternoon! I am pleased to join Jim Baca of the New Mexico State Land Office in welcoming each of you to this week's Piñon-Juniper Symposium.

First, I want to take a moment to recognize the Chairpersons for this year's symposium. They have worked hard and have done a great job! If Jeff Kline of the New State Land Office and Doug Shaw of the Watershed Staff of the Forest Service office in Albuquerque are in the audience, will you please stand? Jeff and Doug shared the responsibility in putting this conference together. Let's give both of them a big hand. Thanks, Jeff and Doug.

I also want to thank the New Mexico State Land Office for providing us with a meeting place.

And thanks to the Santa Fe National Forest for taking time out of their busy schedule to host a field trip on Wednesday.

This is not the first Piñon-Juniper Symposium to be held in New Mexico. However, I think this meeting is unique compared to previous conferences. Why? In reviewing this week's agenda, I noted three general promotional themes:

1. Building partnerships
2. The piñon-juniper ecosystem is a special place
3. All is not well in our P-J ecosystems.

BUILDING PARTNERSHIPS

I would like to briefly address each of these three themes. First: building partnerships. For those of you who may not be aware, about three weeks ago the New Mexico Legislature passed a memorial highlighting the many issues surrounding the piñon-juniper (P-J) ecosystem. But more important opportunities were also mentioned. With this in mind, the Legislature called upon all appropriate federal and state agencies, county governments, tribal governments, research and educational institutions, non-profit organizations, as well as individuals and groups with a vested interest in the piñon-juniper ecosystem (such as the ranching community, the piñon nut industry, and many others), to join as partners to seek workable solutions to the many problems and management questions related to piñon-juniper woodlands. It was in this same spirit of working together through partnerships that each of you was invited to participate in this week's symposium. **Your input is critical to all of us: what you have to say is important in the success of building true partnerships.**

Although this symposium is sponsored by New Mexico State University, New Mexico State Land Office and USDA Forest Service, the list of P-J partners exceeds 20 in number — too many to name at this time. I hope that by the end this week, the number of partners will have increased as well as the number of working relationships.

THE PIÑON-JUNIPER ECOSYSTEM IS A SPECIAL PLACE

I also mentioned the theme, "The piñon-juniper ecosystem is a special place." Some lifestyles such as ranching make their livelihood from the P-J ecosystems. Cattle grazing has been part of the P-J for several generations.

Equally important, the P-J ecosystem is essential to the survival of the Hispanic and American Indian cultures — especially to the American Indian. We cannot talk about the American Indian of the Southwest without talking about P-J ecosystems and vice versa. Piñon-juniper is part of the architecture of historical cities such as Chaco Canyon. Hundreds of villages of the era from 750 to 1300 AD occupied the present day P-J ecotypes. Direct descendents of these early day users are participants in this symposium. Some attendees, some as speakers and others as active partners, are part of the list that I spoke about a moment ago. Piñon nuts, fire wood and other wood by-products are still very much part of these two cultures. These and other by-products have become important to other cultures as well.

To many of us, the P-J ecosystem has become the place to recreate. This includes, but is not limited to: cross-country skiing, hunting, hiking, bird watching, camping, weekend/afternoon drives, and family outings such as cutting fire wood and collecting piñon-nuts.

The various P-J ecotypes serve as home to hundreds of different types of wildlife, including both large and small mammals such elk and field mice. The ecosystem is a home to a variety of birds and a resting place for neo-tropical birds. The P-J ecosystem hosts a variety of plant communities ranging from grasses to shrubs that provide forage for the livestock we graze and the wildlife we hunt and supports the shrubs that we

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[2] Deputy Land Commissioner, New Mexico State Land Office, Santa Fe, NM.

transplant to our front lawns as decorative items to make our home beautiful and to raise its value.

To all of us, the piñon-juniper ecosystem is a giant watershed that provides the water we drink. Healthy P-J ecotypes are the lifelines to quality that we expect each time we open the faucet in our home. Healthy P-Js are the lifelines to the water we use to bathe and to water our lawns. Healthy P-J is the source of quality water that is delivered to huge reservoirs where we recreate and store the water that is used to irrigate the hundreds of thousands of acres of food crops. It is the watershed for people outside of New Mexico as well, such as those from Texas and across the international boundary into Mexico.

Equally important, healthy P-J ecotypes are the monitors of our ability to care for the land and maintain soil productivity. A healthy P-J ecosystem increases our ability to keep soil in place rather than eroded far away, polluting our streams, rivers, lakes and reservoirs.

Yes, P-J is a very special place. It has been a special place for hundreds of centuries. It is special today and will remain special for years to come.

ALL IS NOT WELL WITH OUR PIÑON-JUNIPER ECOSYSTEMS

The third theme that I note in the agenda is that all is not well with our piñon-juniper ecosystems. The book, The Great River, documents the diary of a Spanish officer located here in Santa Fe. This officer was among the first Spaniards in this area. He writes of his concern that it had been two days since he sent a patrol of soldiers to collect firewood. He also writes of the tall grasses around Santa Fe and surrounding country. A quick glance at present-day Santa Fe will tell us that much has changed in the last two to three hundred years in terms of vegetation and forage production. Recent photos indicate that major changes in terms of soil production have occurred in the last 100 years. A quick visit to the Rio Grande and places like Elephant Butte Reservoir will demonstrate that soil loss and reduction of water quality are much greater than what would occur from natural processes alone. A visit to our P-J ecosystem will show unacceptable amounts of bare soil, depleted top soil, and vegetation cover. We are not talking about natural process, but over and above natural erosion processes. We are talking about the results of imbalances created by people; not only imbalances that were created 100 years ago, but, more importantly, those imbalances that we are allowing to occur today.

I recently overheard a comment by a land manager that it was too expensive and that funding is not available to restore the unacceptable condition of the P-J ecosystem. This individual's assessment is probably true. But, it is also true that we cannot afford to continue with our present attitude. The present unacceptable condition could be the result of lack of funding and/or it could be the result of present management practices.

Our challenge is to do better in both understanding and managing this forgotten natural resource heritage. In the past, we have studied and managed mainly according to biological importance and, in most cases, for a single resource. Can we continue with this process? Or would it be better to widen our views to ecosystem management — to include the biological, economical and traditional social-cultural needs?

I doubt if all the questions and concerns that will surface during this week can be answered. On the other hand, the make-up of the agenda and the attendees will help raise the awareness of the complexity of the economic, social, and natural resource needs within the P-J ecosystem. Individual concerns and comments are important — as will be networking during designated breaks or whatever other opportunities may exist to exchange ideas and build partnerships to continue to make piñon-juniper a special place, as it has been for hundreds of years.

I encourage each of you to participate in the symposium as much as possible and to have an enjoyable and productive week. Thank you.

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Bob Langsenkamp...

On behalf of Commissioner Baca I'd like to welcome you all here today. He can't make it for reasons which are known to most of you. Commissioner Baca may soon have responsibility for much more P-J Woodland than he has now, and that makes the information, goodwill and enthusiasm you generate here all the more important. He will have his confirmation hearings for BLM Director before the Senate Energy Committee tomorrow morning.

Like many of the most important things in life, modern society in the Southwest has tended to take the P-J Woodlands for granted. It is certainly true in my case, being a product of this society. As a teenager in southwest Colorado, P-J was just a rather scraggly, unattractive ecotone that one had to travel through as a necessary transition to get to more exciting things like elk (elk in the woodlands were almost unheard of then) and trout at the higher elevations, or to get to my summer job as a choker setter on a logging crew in the more valuable (I thought then) mixed conifer or Ponderosa. These were the sensibilities and aesthetics of an adolescent.

Maybe living in the P-J Woodland for much of the last 30 years has finally given me an appreciation for it, or more likely society in general, has matured in its understanding and appreciation of P-J and has pulled me along with it.

The fact that this symposium is occurring at all is testimony to the fact that there is greater appreciation and understanding of our woodlands, much of which is due to the work of many of the people who are in the audience and who will be on the panels. We obviously have a long way to go, but maybe will we will mature enough as a society in the west to approach the woodlands with the same wisdom as those who have lived on a sustainable basis in the woodland for generation after generation. So, let's get on with the work of exploring how we practice the art of piñon-juniper woodland with great enthusiasm and flourish.

My Vision of the Piñon/Socioeconomic Potential of Piñon Woodlands

Jeff Kline[1]

State Land Commissioner, Jim Baca, is today appearing before the US Senate Interior Committee on his nomination as Director of the BLM. Much of what I have to say has been developed in discussions with Commissioner Baca. This conference is in many ways a tribute to Jim Baca's vision of keeping all our lands productive and beautiful. These goals are also in line with the whole-system ecological management principles being articulated by our new State Land Commissioner, Ray Powell.

I want to personally thank Mr. Doug Shaw of the US Forest Service whose hard work over a period of six months has brought this conference together. The purpose of this conference is to give all of us a chance to learn from each other and to discuss new ways of managing the complex ecosystem known as the piñon juniper woodlands as a positive resource in its own right.

How did our woodlands become so degraded? Why is it that in the rest of the world people are planting trees to stop erosion, but in the American Southwest there is a belief that piñon and juniper trees cause erosion? Are piñon trees really invaders? Is the highest and best use of our piñon and juniper woodlands for livestock grazing?

To talk about the future of our woodlands, we must first look at the past—I want to give you a sense of the tremendous pressure our woodlands have been under during the 400 years of European domination of the American Southwest. Then I want to talk about the importance of piñon nuts to the traditional people and cultures of the Southwest, and how we can use piñon nuts as a product or reason to justify positive management of the woodlands for food products like piñon nuts, bio-diversity, and watershed improvement in a manner that will elicit public cooperation. Finally, I want to describe some of the areas for research and silvicultural practices that need further work so we can properly manage the piñon and juniper woodlands—the ecosystem where most people actually live.

I'm sure most of you know that piñon trees grow in some relationship with junipers and that junipers dominate in lower elevations and piñons at higher elevations. Rocky Mountain Juniper known as "Cedro" to Spanish Americans dominates in higher elevations and one seed juniper and alligator juniper at lower elevations and latitudes. The two major species of piñons are Pinus edulis in New Mexico, Colorado, Utah, and Eastern Arizona; and Pinus monophyla in Western Arizona and Nevada.

I will refer mostly to piñon trees, but in so doing I am speaking about the entire ecosystem.

When I was a child in Los Angeles in the early 1950's, I loved climbing the California Live Oaks around my home. By the time I finished college at Berkeley and Santa Cruz, most of the oaks around my parents' home had died; in fact, most of the oaks in places like Encino (Spanish for Oak Tree), and Thousand Oaks and all the oaks in the canyons between Los Angeles and San Fernando had died. Today people probably wonder why they named those towns after trees that don't exist. But they did exist, I played in their branches and I mourned their passing. I honestly believe that we humans have a spiritual connection to trees. Especially long lived trees like the oaks and the piñon pine. In Cosmos, Carl Sagan said that genetically we have more in common with trees than we have differences.

I came to New Mexico in 1969 and settled in a small village called Las Trampas inside the Penasco Ranger District of the Carson National Forest. I made adobes and lived without electricity or running water. In the summers I worked fighting forest fires. In 1972 I participated with some of my neighbors in an economic stimulation project to cut down live or "green" piñon trees. The cooperative only wanted us to bring in the trunks of live piñons which were split and wholesaled as firewood to cities in Colorado and Texas.

This requirement to cut live trees went against all my training as a Boy Scout, but I was the new-comer so I bought a chain saw and went along with my neighbors. At that time the Penasco district was covered with a climax forest of large canopied piñon trees—the size and shape you could ride a horse under. After a month of cutting big piñons, one of my older neighbors, the husband of the postmaster, Delfido Lopez, told me that we young men were "cutting the throats of the villagers". He explained that with our 4-wheel drive trucks and chain saws, we were removing the last of the big piñons—the ones whose branches had supplied firewood to the villagers for 400 years and whose nuts had fed them. I told him not to worry, that the trees would grow back and I doubted his claims that in areas where there are small piñons today there used to be the same big climax ones I had ridden my horse underneath. But Delfido was right and I and the other young men were wrong.

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The reason we didn't see any stumps indicating the huge piñon trees that used to grow on the hills around the village is that there is a certain species of red ant that loves to eat the stumps of piñons. That is why one does not see the stumps of the old piñons the way you can see the stumps of the huge ponderosa pines that once held sway here. The ponderosa stumps may be protected from the ants by their high turpentine content. In any case, the ants eat up the piñon stumps in one or two seasons.

When you came in the foyer of the Land Office you may have noticed a 600 year old piñon trunk on display. I purchased it from Mr. Valdez's woodpile in Tierra Amarilla. Mr. Valdez told me the tree was still alive when he cut it down last August. The tree-ring lab at Tucson dated the birth of that tree to the year 1390--a century before Columbus set sail for the new world. In fact that tree was already more than two centuries old when the first European colonist, Juan Onate, invaded New Mexico in 1598.

Here are some smaller specimens: This 18-inch diameter one dates from 1620, just after the founding of Santa Fe. This 8-inch one began growing before the signing of the Declaration of Independence and this 5-inch diameter trunk of a piñon tree, cut live by NMSU researchers in 1983, is 250 years old! Piñon trees grow slowly.

The European colonists who came here in 1598 were into resource extraction in a serious way. Piñons and junipers grew closest to their settlements--so the tallest and best piñon and juniper trees were used for lumber and hand hewed with adzes. Piñon and juniper timbers were used for construction in the 1600's--but it was the constant demand for firewood that really took a toll on the post-conquest forests.

The Spanish settlement of Santa Cruz de la Canada near Espanola was the largest European settlement north of Guanajato on the North American Continent during the early 1600's. A thousand homes burning 10 piñon trees a year in the Santa Cruz and Chimayo valleys would have consumed 10,000 trees a year--not so much you might think. But multiply that times the 400 years of European occupation and it adds up to a whopping 4 million piñon trees. When I did the arithmetic I realized that the fuel wood harvest over the 400 years of continuous occupation exceeded the total number of trees growing in the watershed. In fact, fuelwood harvesters must have completely deforested the hills around the old settlements. I began to realize that the small misshapen little bush-like piñons and junipers growing on the hills around the old Spanish villages were not the result of some natural selection, but rather evidence of human impact.

In 1972 a U.S. Forest Service silviculturist described the New Mexican woodlands near the old Spanish settlements and Anglo-American mines as evidence of a new phenomenon he termed "Reverse Genetic Selection." Only the worst trees were left to survive.

When I researched the customs of the Northern New Mexican villagers for my Masters Degree in the early 1970's, I learned that they used to deliberately cut down all the woodland trees around the isolated villages to protect themselves from Indian attacks. As time progressed, with the arrival of the American occupation in 1848, the harvest for firewood intensified. Commanders of forts in the late 1800's had a bunch of men in a corral with not much to do so they sent them out to cut down all the woodlands trees and bosques to deprive Indians of cover. When the railroad arrived in the 1870's it didn't run on coal- it ran on piñon. Because piñon trees are so old, they burn hot. The Denver Rio Grande narrow-gauge, for example, burned piñon exclusively. Men with no other source of income fanned out with burros to extract this resource. In Nevada every piñon and juniper within 80 miles of the silver smelters was cut and reduced to charcoal. The devastation of the woodlands was so complete that the miners had to resort to making charcoal out of sagebrush.

When people point to the old photos from the late 1800's and early 1900's they claim that the piñon trees are invading because no trees were in those old photos. However, those researchers need to study the impact of human history on nature. Those photos were all taken from places like Fort Stanton or old settlements like Santa Fe or around mining and railroad sites. The photos document the resource extraction and devastation wrought by settlers and soldiers, in an era when European man was at war with nature and was deliberately attempting to exterminate Native Americans and their food sources.

Livestock grazing in the Southwest peaked in August of 1890 when millions of head died off because there was no longer any grass. The formation of many arroyos also dates from August of 1890 when newspapers first reported their mysterious creation. The tremendous overgrazing of the late 1800's did destroy the native perennial cool season grasses (many of which either became extinct or never re-established viable populations), and paved the way for the massive non-point source sheet and rill erosion which has denuded the woodlands of their original topsoil--preventing the regrowth of those grasses today.

No one knows for sure if the amounts of grasses growing in the woodlands prior to European Colonization was enough to sustain fires that might have naturally thinned the woodlands but we do know that, in most cases today, there is not enough natural ground cover to do so.

After World War II, the USDA Forest Service and Soil Conservation Service in an effort to increase forage for livestock initiated a number of programs and incentives to fund private landowners and public land agencies including Indian Nations to convert woodlands into pastures. Piñon trees and junipers were classified by the SCS as "brush" (subject to "brush eradication"), and the American woodlands were placed under the control of range managers (with the mission to increase forage for livestock) rather than under the control of foresters who might have managed the trees as trees. Unfortunately, the chaining, crushing, and poisoning of the woodlands mostly resulted in sagebrush now growing where trees once held sway.

Additional impacts on the woodlands occurred with the "Energy Crisis" of 1973 when the price of propane tripled and a great many rural families decided to switch back to wood for

home heating and cooking. As these families went into the woods they discovered that many of their traditional wood cutting areas had been "converted" to grazing lands. In their frustration, they began "poaching" trees. The piñon again was the favorite fuel wood because it burns so hot. Where families used to harvest branches with axes, men with four-wheel drive trucks and chain saws now scoured for the biggest trees. In fact, it is easier to cut a live piñon with a chain saw than a dead one—and chain saws work most efficiently on large pieces. So they went after the biggest and the most outstanding trees.

Photographs of North Africa today do not give a clue that its hills were once forests. The floods that ravage Bangladesh originate in the deforested Himalayan foothills of Nepal where villagers desperate for firewood for home cooking and heating fuel have destroyed their woodlands. The island of Cyprus was completely denuded of its trees during the Mycenean Era. Arcadia was the Cedar forest on the outskirts of Babylon.

In the Book of Kings in the Old Testament we read that "Solomon sent to King Priam in Tyre for the Cedars to build the 'Beit Ha Kodesh'—Solomon's Temple in Jerusalem." In fact, the Cedars of Lebanon were used to build both Solomon's Temple (around 900 BC) and Nehemiah's around 400 BC after the Babylonians burned the First Temple.

The destruction of the Cedars of Lebanon can be documented in the history of Tyre. Tyre had its own king at the time of Solomon because it was an island citadel. It took Alexander the Great months to build a causeway across the sea to storm it. What happened? Alexander and other conquerors cut down the Cedars, the goats ate the seedlings and so much top soil from the deforested hills of Lebanon washed down that it filled in the sea all the way out to the island citadel of Tyre. Today Tyre is a port city on the coast of Lebanon. This complete destruction of the forests of Lebanon and altering of the coastline occurred during recorded history.

Today Lebanon's flag proudly displays the "Cedar of Lebanon" as its national emblem—however, the nation of Lebanon only has about 40 cedar trees left from a forest of millions. Man can completely alter nature.

The 600 year old trunk of the *Pinus edulis* piñon tree cut live for firewood just this past summer is proof that the Piñon is not invading. Rather it is we who are the invaders—and our challenge is to heal the woodlands and return them to their potential—to the kind of climax and varied woodlands that existed in the American Southwest prior to the arrival of Europeans with their axes, goats, sheep, and cattle.

I realize that it seems like we have an endless supply of piñon and juniper and that our problem seems to be too many trees crowded too close together. No one claims that piñon and juniper trees are endangered species. However, the last remaining old growth piñons and junipers are in danger of extinction. These relic old-growth woodlands are similar to the oaks I climbed in Southern California in the 1950's. These oaks are gone. How many more 300 - 600 year old piñon nut trees will we cut down before we end up like Lebanon, with only a handful of big trees left?

We may not exterminate the species of *Pinus edulis* but through reverse genetic selection we have been diminishing its quality.

One key to restoring the piñon woodlands to their pre-Columbian potential is the revitalization of the piñon nut industry. By showing product-oriented managers and land owners that there is a valuable commodity available from the woodlands that can be harvested without disrupting the natural ecology—we provide an economic incentive for correct ecological practices.

Even the most high minded foresters need the cooperation of the local inhabitants of the rural areas surrounding the forests if their policies are to work.

In Brazil, where cattle ranchers avidly set the rain forest on fire to create pastures which are depleted in a few years, a non-profit group called "Cultural Survival" has created a market for the Brazil Nut as an economic inducement for the Indians and local population to preserve the rain forest as a bio-diverse ecosystem. Cultural Survival Foundation helped broker the deal with Ben & Jerry's Ice Cream to use Brazil Nuts in their popular "Rain Forest Crunch" ice cream. We will learn more about this from Jason Clay of the Foundation later in our agenda.

This same kind of inventive marketing could be used with our piñon nuts as a reason to elicit public cooperation in better management of our woodlands.

The way to maximize product and profit from the woodlands is not by trying to change the dominant vegetation from woodland to grassland but rather, to look at the potential resources and values already existing in the woodlands.

When the Spanish Conquistadors arrived they recognized the value of the piñon nuts and made them the primary commodity exported back to Mexico. They even used piñon nuts for cash.

Piñon trees grow around nearly all the ancient Anasazi sites and most modern Indian Pueblos, and provided a key source of winter protein. Piñon nuts are what sustained the survivors of the ill fated Donner Party trapped in Sierra snows. During the 1920's entire railroad trains were filled with box cars loaded with Piñon nuts which were exported to New York and on to Europe. The 1936 harvest exported out of Gallup was 8 million pounds. At today's prices that would be a 48 million dollar crop. Million pound crops continued to be exported to New York throughout the early 1940's. During this same epoch, rural families would collect up to 2 thousand pounds of piñon nuts per household for personal consumption, and they would even cook the excess nuts and use them for cooking oil instead of lard.

In terms of economics, New Mexico State University published an interesting study by John Fowler in 1987 on the economic value of the products of the piñon-juniper woodlands. In summary, Fowler found that the value of the forage available in the woodlands amortized on a sustained yield basis comes to $2.90 per acre at today's prices. In comparison, Fowler also calculated the value of the piñon nuts available on the forest floor on a sustained yield basis is to be $300.00 annually at today's prices. (Based on 250 pounds of nuts per acre times

$6.00 per pound (avg price 1988- 1992) = $1,500.00 worth of nuts per acre in a good year, divided by 5 (most areas produce a good crop every 5 years) equals an annual value of $300.00 per acre per year).

Therefore, management of piñon woodlands for nut production will yield ONE HUNDRED TIMES MORE REVENUE PER YEAR than will management for forage. And, livestock grazing can still continue in the woodlands without detriment to nut production as long as the overall management objective is bio-diversity and production of piñon nuts rather the forage production.

Now what makes more sense, managing woodlands which grow primarily on rocky soils in order to generate $3 worth of forage per-year per-acre or managing woodlands which can generate $300 per acre in piñon nuts for nut production? Well, if I owned 2.4 million acres of piñon woodlands as the U.S. Forest Service does in New Mexico, and I wanted to maximize profits and provide incentives for rural economic development, and if I acknowledged that the value of the forage was $7,200,000 per year, and the value of the piñon nuts was $72,000,000 per year I would certainly make production of piñon nuts my primary objective and forage a secondary benefit. Furthermore, managing woodlands for piñon nuts is symbiotic with trying to create biodiversity.

Surprisingly, Fowler calculated the value of fuelwood on a sustained yield annual basis to be only $6.66 per acre based on a $95 per cord average price. This is also based on Fowler's study showing growth in the woodlands to be only 0.07 cords per acre based on a 180 year rotation. Today, most foresters are using a 200 year rotation for to calculate sustained yield in the piñon woodlands, so the actual growth of mass for fuelwood is closer to 0.06 cords per acre.

Therefore, managing piñon woodlands primarily for fuelwood or forage as a primary product is a gross mis-use of the resource. Incidentally, Fowler also calculated the value of wildings to be $719.00 per acre (based on 10 - 7.5 foot trees at $9.50 per foot) and the value of Christmas trees to be $574.00 per acre (based on 10 - 6 foot trees). Fowler did not calculate any value for other woodlands products like juniper branches for Christmas tree wreaths.

So the amazing result of these scientific studies is that management of the resource for fuelwood harvests in excess of 0.06 cords per acre (the sustained yield harvest) is a gross waste of a resource which can provide $300 of piñon nuts per year. Surprisingly, in both the Santa Fe and Carson National Forests, stands of 200 - 600 year old piñon nut trees are still being eradicated for fuelwood harvests at rates thousands of times in excess of the allowable sustained yield!

Incidentally, the State Land Office currently leases grazing rights in the woodlands for around 60 cents per acre. If we separately leased easements for the collection of piñon nuts, and charged 10% of the value of the nuts, we could be earning an additional $25 per acre. If our primary goal is to protect the Trust resources while maximizing income, it seems clear that with the 1,160,000 acres of State Trust Land in piñon-juniper woodlands, we could be making $29,000,000 in additional revenues each year from lands which are currently only generating $696,000 in grazing revenue. And, the grazing can even continue. The harvest of piñon nuts would simply be an easement on top of the grazing leases. Even if our revenues were only one percent of the value of the piñon nuts, they would generate nearly three million dollars a year in revenue and more than pay for positive management of the resource.

You might ask, what is the demand for piñon nuts?

The answer in all the rural communities bordering woodlands is lots. Native American and Spanish Americans love to eat piñon nuts, and millions of pounds are harvested every year for personal consumption providing supplemental food, and supplemental income.

The demand for piñon nuts at the wholesale level is even larger. This year the United States imported 2 million pounds of shelled pine nuts primarily from China and Portugal. The price paid for these pine nuts at the docks in New York and San Francisco averaged $6 per pound in 100,000 pound sub-wholesale loads unloaded off ocean freighters. These nuts are then sold to restaurants, confectioners, pesto makers, and nut companies at prices averaging between $8 - $12 per pound. It is hard to believe, but tonight if you were to treat yourself to dinner at one of Santa Fe's most famous restaurants, the Coyote Cafe, where the fixed price dinner costs about $40 per person, and the where the Cafe promotes itself as serving cuisine based on Native American foods, the pine nuts garnishing the desert are not Southwestern Piñons, picked by Native Americans or Hispanics, rather they are imported Chinese pine nuts.

Surely the fancy restaurants of Santa Fe would do better to serve the nuts grown here and in fact, even the pesto makers of Massachusetts would probably sell their product for a higher price if they could claim "wild Southwestern Piñon nuts" as an ingredient.

As Jason Clay from Cultural Survival and Susan Curtis from the Santa Fe School of Cooking, will be explaining, the market for piñon nuts does not end here. There is potential demand for piñon nuts as ingredients in a number of sauces. They can also be used as an ingredient in "nut flours" popular in health food stores. They can be used as high priced cooking oils. Rancid or excess nuts can be used as animal feeds (with the shells) and the shells can be used for other purposes as can the oil. Special high value charcoals from piñon nut shells can be sold to Japan which pays incredible prices for specialized charcoals to be used in their national pastime of Hibachi cooking.

Other woodlands products could include using juniper shavings in dog beds.

Clearly, whether the land manager be an Indian Nation or the USFS seeking to stimulate rural economic development, or an agency like our State Land Office, seeking to maximize revenues, opportunities to derive products and profits from the woodlands in a manner that does not degrade the woodlands or diminish their capacity as watershed, are greater

when the woodlands are managed viewing the trees as a positive resource than when they are managed with a view towards eliminating the trees.

The dominant species of piñon in New Mexico and Colorado is the Pinus edulis—Latin for edible pine. It takes three growing seasons to produce each piñon nut. The first season is microscopic development in the growth tip. The second season one sees the small brown "dime-sized" conelets. In the third season the conelets develop into bright green small cones which begin to enlarge and exude piñon pitch. After the first frost these bright green cones turn brown and open, releasing the wingless seeds (piñon nuts) to fall to the litter under the trees.

According to Elbert Little the Spanish word "Piñon" is not the diminutive, but rather the superlative, denoting in Spanish the largest edible pine nut. Anyone who has tasted the pine nuts of the world knows that Pinus edulis nuts are the most delicious pine nuts of all—better tasting than the pignoles of Italy, Spain, and Portugal and better than the Chinese and Korean pine nuts. That is why our piñon nuts are preferred by nut companies for raw and roasted nuts and why they are valuable in candies, cookies, and deserts. The dominant species in Western Arizona and Nevada (Pinus monophyla) would be perfect for cooking oils on account of its creamier texture.

In his wonderful book, "The Piñon Pine," published by the University of Nevada, Ron Lanner has an inspiring chapter where he talks about the potential of the North American woodlands to provide the pine nut protein for the rest of the world. Not only as nuts for eating, but also as a basic food product for cooking oils and other uses.

The Forest Service and SCS are services of the Department of Agriculture. Considering that the value of the protein from piñon nuts far exceeds the value of the protein from beef which can be raised where the piñon-juniper ecosystem is the dominant vegetative type—it is clear that as part of the mission of the Department of Agriculture, the Forest Service and SCS should be managing the woodlands for nut production rather than for forage. Also, for traditional minded foresters, the other woodlands products, fence posts, fuel wood, wildings, and Christmas trees can all be harvested from the woodlands on a sustained yield basis and will bring to the federal treasury far greater returns than can be gotten by ignoring those resources and concentrating on forage.

Similarly, BIA foresters should be encouraging traditional uses of the woodlands for nut production and the BLM can expand upon the leases it is already offering for commercial harvest of piñon nuts.

In conclusion, the desired future condition of the woodlands includes piñon and juniper trees of varied ages including climax trees with canopies spaced appropriately for maximum production of piñon nuts. It includes forbs and grasses, both cool season and hot, growing under and around the trees. It includes good watershed retention and an abundance of diverse wildlife.

The sociological picture includes local residents using the woodlands for economic gain. Locals can gain supplemental income from supervised and contract fuel wood harvests. Incidentally, fuel wood sales in the Carson have often brought higher value to the Forest Service per-board-foot than timber sales. It will include locals harvesting wildings and Christmas trees. It will include local families harvesting piñon nuts under "free use permits" for personal use as supplemental food and supplemental income. It will include commercial harvesting of piñon nuts by local residents and Native Americans to satisfy the world market.

It includes ranchers continuing to graze on woodlands where appropriate and at stocking levels that will allow the grasses to finally re-establish themselves. This may mean removing or restricting grazing from areas for several years during re-seeding projects.

It includes the Forest Service, BLM, and Indian Nations using U.S. Department of Labor funds to hire teenagers and older citizens to do labor intensive silvicultural practices including basal pruning of piñon trees to increase nut production, and pruning juniper trees to stimulate them to grow straighter to produce better fence posts and to grow straight grained cedar wood for high-value fine furniture.

This socioeconomic vision means that the rural residents and the land managers will be working together for the common good.

In New Mexico we've already taken some first steps: In 1987 we passed the Piñon Nut Act, and this year the Legislature amended the Act to strengthen it. The Act has two main components: The first section, enforced by the New Mexico Department of Agriculture, makes it illegal for anyone to market a product as "Piñon Nuts" unless they really are North American piñon nuts. This will serve as an incentive for local businesses and restaurants to purchase our own native grown and locally harvested piñon nuts. Stimulating demand gives resource managers more reason to provide supply.

The second section of the Act requires New Mexico State University to devote an appropriate portion of its funding to genetic research related to piñon trees and to developing a seed source for reforestation of piñons. The Act also requires NMSU to do research into diseases afflicting piñons, conduct marketing studies, recommend storage and packaging techniques for piñon nuts, publish complete nutritional analysis, develop mechanical means for harvesting the nuts without harm to the environment, and develop shelling machines.

However, the research agenda laid out in the Act needs to be carried out by someone if we are to realize our dream of providing the incentive for positive management of the piñon woodlands in a manner that will provide economic incentives to rural residents.

Who will seek out, collect, and warehouse the best seeds for future piñon and juniper reforestation projects? What will be the criteria for seed selection?

Can we clone these trees, or cross-fertilize seeds to get trees that will bear partial crops every year? Can we create trees that will grow quickly and still be drought and freeze resistant?

Can someone develop a back pack type battery powered vacuum that can be used by individual harvesters on foot to suck up piñon nuts from the forest litter while screening them and returning the rest of the litter to the ground under the trees, thereby increasing the quantity of nuts that individuals can harvest to make it more economical and efficient for people to harvest nuts without harming the trees. Perhaps, the USFS Forest Products Lab could begin work on this.

Who will determine how many nuts need to be left for wildlife and natural regeneration?

Wouldn't it be appropriate for the USDa itself to study and publish a complete nutritional analysis of Pinus edulis and Pinus monophyla piñon nuts (and a comparison with european and Asian pine nuts). Retailers are already asking for this information to put on their packaging!

Can the USDA and the U.S. Department of Commerce develop criteria regarding the proper (bonded) warehousing of piñon nuts so that Indian Trading Post operators can provide third party certification to bankers to help them finance purchase of the entire crop during bumper years—which will also allow them to keep up the prices they pay the pickers.

Can't the USFS's own seed storage labs begin work on storage techniques for piñon nuts so that when we have a bumper crop like 1992's ten million pound harvest, we can economically put some of the crop away to level out supply and provide for blight years so that retailers can always depend on the Southwest for product and cease their reliance on China.

And the sheller: one reason the fancy restaurants buy pine nuts from China and Portugal is that they come already shelled and vacuum packed. We need to have shellers available so that small businesses and Indian Nations can shell and vacuum pack their product here and thereby command higher prices and be able to meet market demand.

So, what stands in the way of developing our vision for the woodlands?

1. We need a clear directive from upper level management, that the woodlands are a positive resource to be managed as a complete ecosystem—rather than something to be converted into grazing forage. Thanks to courageous leaders like Jim Baca and to the new focus of the U.S. Forest Service in Region 3—led by Larry Henson who has placed management of the woodlands under the watershed team, and thanks to our new State Land Commissioner, Ray Powell--this is happening. However, these leaders, as well as everyone with an interest in the woodlands need to stay focused. It will not be easy to reverse 400 years of neglect.

2. We need landscape objectives to help us visualize what would be the optimum woodlands density, spacing, age diversity, bio-diversity, canopy cover, etc., for each of the various soil types and climates. We need everyone's help in drawing a picture of the desired future condition. We need for USFS District Rangers and other land managers to experiment with silvicultural practices on small plots of woodlands and to set up transacts to study optimal pruning and thinning prescriptions. We need experiments done for careful thinning when small trees are growing too close together. We need manager's to experiment with pruning branches and using the branches to stop erosion in arroyos without removing whole trees. We need people to experiment with different cool and warm season grasses to try to stop the rampant erosion. Most of all, we need managers to set aside areas as potential "piñon nut" orchards—for the primary purpose of serving as recreational areas for the gathering of piñon nuts. Such areas should be posted so that fuel wood poachers will think twice about cutting down food producing trees.

3. We need help from economic development specialists to revitalize and modernize the historic piñon nut industry—an industry whose annual sales can easily exceed 100 million dollars throughout the region, and provide direct income to many rural residents and Native Americans.

I trust that many of you here today will do this work. In so doing you will help restore the most vital ecosystem in the Southwest—the piñon-juniper woodlands—the ecosystem where most people live; and you will be proving that ecologically sound management is also good for the economy.

Ecosystem Management in the Southwestern Region

Cathy Dahms[1]

On June 4, 1992, Forest Service Chief F. Dale Robertson committed the National Forests and Grasslands to ecosystem management. The Forest Service has defined ecosystem management as using an ecological approach to achieve the multiple-use management of National Forests and Grasslands by blending the needs of people and environmental values in such a way that National Forests and Grasslands represent diverse, healthy, productive, and sustainable ecosystems. Sustainable ecosystems are not only those that provide for the health and resilience of ecological systems and processes, but also provide for sustaining the health and vitality of the people who depend on the land for their livelihoods, outdoor recreation opportunities, and inspirational experiences, as well as sustaining economic prosperity

In implementing ecosystem management, the focus will be on desired present and future conditions of the land and its human communities at multiple scales, always striving to maintain a balance between sustaining the resource itself (diversity, health, and productivity), lifestyle or social goals (attractive appearance of the landscape, health factors, understanding historic use and cultures, current human values and use patterns, inspirational areas, religious values, customs and tradition) and economic goals (economic productivity, economic importance, jobs, diversity of products, recreational opportunities). If the desired conditions for these three areas are represented as circles, the goal of ecosystem management for the overall landscape would be somewhere within the intersection of the three circles. While striving to meet this generation's resource needs, we must be careful not to make any irretrievable resource decisions that would limit the ability of future generations to also meet their needs.

The key difference between ecosystem management and Forest Service resource management of the past is that under ecosystem management, we look at the whole picture over space and time, while in the past, we tended to examine each resource separately and within units or aggregates of units of land at the stand level. Focusing on ecosystems is a shift in our thinking--many people have referred to this as a paradigm shift. According to Joel Barker, a paradigm shift is an action that creates new opportunities where:

(1) It happens before you are ready and those who take early action profit greatly.

(2) Comes from people who do not know your business. While ecosystem management was an evolution from the Forest Service's New Perspectives program, there were many other national and international efforts that promoted taking an ecological approach to management.

(3) Requires more courage and intuition than data. This is encouraging because we'll never have all the data we'd like to have. It has been said that not only are ecosystems more complex than we think, they are more complex than we can think.

(4) It changes the rules.

Also, ecosystems do not fall conveniently into our administrative, ownership, and jurisdictional boundaries, and frequently cross ownership boundaries. This calls for greater cooperation and coordination of goals and planning effort's with the landowners involved.

In addition, we recognize that ecosystems occur at different geographic scales. A National task team is working on a hierarchical framework of ecological units and have proposed the following overall scheme. At the Region level, represented by U.S. map scales of 1:30 million to 1:7.5 million, broad analysis and modeling would occur. Landscape level analysis at 1:100,000 to 1:24,000 would most likely occur at the Forest planning level, while planning for ecological land units at the 1:24,000 scale would occur during project planning. Because ecosystems occur at different scales, we are faced with the challenge of considering the effects of our proposed actions at several geographic scales as well as through time. When planning at the local or landscape level, we must recognize that our choices also affect the continental and global economy and environment. As a rule of thumb, we need to consider effects of proposed actions at least at one scale larger and one scale smaller than the scale we are working with, and for a minimum of several decades into the future.

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To meet this challenge, the Southwestern Region and the Rocky Mountain Forest and Range Experiment Station jointly developed an umbrella strategy to guide the 11 National Forests and 3 National Grasslands of the Southwestern Region in the implementation of ecosystem management. The strategy examined where we are today and where we want to be in the future. Some of the key goals in our vision for the future are:

1. To have forest land and resource management plans that reflect programs and methods that are socially responsible, scientifically sound and, at broad scale land areas, are managed within long-term ecosystem capabilities or sustainability.

2. To develop a desired future condition (DFC) integrating the needs of people, land, and resources and is both site and landscape sensitive as the starting point for all projects. Cumulative effects are assessed through time and space. The goal of planning and implementation is to progress toward the desired future condition. Monitoring and evaluation are systematically carried out to determine effectiveness and validity of plans and practices and the results incorporated into forest and project level plans.

3. To approach land management from a holistic perspective, rather than for single resources.

4. To have an interactive program explaining the workings of southwestern ecosystems available to Forest Service employees and interested outside parties.

5. To have integrated resource inventories and analytical techniques in place that are cost effective to deal with the spatial and temporal aspects of ecosystem functioning at the landscape level.

6. To focus as much as possible on managing ecosystems rather than managing individual species.

Our next step was to expand our vision into a strategy document. In the development of our strategy, we actively solicited the input of the public, Forest Service Research, and employees at all levels of the Region. Ten elements formed the backbone of the strategy: public involvement, conservation partnerships, demonstration projects, improving our ties with scientists, our forest and project planning process, monitoring, classification and integrated inventories, new technologies, staffing and training, and the evaluation of our progress and performance.

Three of these elements (public involvement, partnerships, and ties with scientists) reflect the teamwork that is essential for the success of ecosystem management. More than ever before, we are committed to public involvement and need to solicit and incorporate people's views into our management decisions. As part of our strategy, the Region developed public participation standards to provide consistency in our public participation process. Coupled with public involvement, we must expand our partnerships with agencies, organizations, individuals, and anyone else who has a shared interest in the management of the National Forests and Grasslands. Our strategy encourages partnerships at all levels - not only do we need to work with the local communities to help them achieve their long-term social and economic objectives, but we also need to encourage partnerships at the forest and regional level to coordinate our management of regional, national, and even international ecological systems such as the Colorado-Rio Grande Rivers or the Chihauhan Desert. The element of stronger ties with the scientific community is also a critical element, to make sure our decisions reflect the best science available. One of the ways we are forging stronger partnerships between the Region, Station, publics, and other scientists is by holding joint seminars, conferences, and symposiums such as the one today. We have also formed a scientific study team to refine our understanding of ecosystem processes and the acceptable range of such processes in terms of sustainability at different scales.

For the next two years, the Region will have demonstration projects at each Forest for interpretation, professional development training, and conservation education on ecosystem management. This doesn't mean we will not be applying the goals and guidelines for ecosystem management in our other projects, only that these projects have been selected for educational purposes. From a practical standpoint, these are also the projects for which we will be using advanced technology. The Forest Service has not yet awarded their contract on Project 615 to acquire Geographic Information Systems (GIS) technology nationwide, so not all of our Districts can take advantage of the spatial analytical abilities of GIS. The majority of our demonstration projects will be using GIS, videography, Landsat imagery, and/or Global Positioning Systems technology. Also, our demonstration areas are looking at larger areas than we have in the past - 50,000, 100,000, even 250,000 acres at a time.

To incorporate ecosystem management in our forest and project planning process, our key strategy will be to develop regional policy and guidance to define the Desired Future Condition concept, describe how planning areas and/or management areas will be based on ecosystem management within the landscape context, and to describe how effects on ecosystems and cumulative effects at larger scales will be analyzed. The Region has a project implementation guidebook (Integrated Resource Management) and has committed to

revising the guidebook by October 1993 to more fully integrate the principles of ecosystem management into our planning process.

Since forest health is one o£ the key goals of ecosystem management, we also plan to capitalize on our Regional Initiatives that are focusing on restoring ecosystem health and productivity, i.e., the Forest Health Restoration Initiative, the Piñon-Juniper Initiative, and the riparian issue. The Forest Health Initiative, for instance, is an initiative covering the complex ecosystems of ponderosa pine, mixed conifer, aspen, spruce-fir, woodland, chaparral, and riparian areas of the Southwest. The structure and composition of these ecosystems on National Forest Service lands have changed significantly since European settlement in response to both management activities and climatic events such as periodic drought. The initiative calls for an accelerated effort to restore overall forest health so that anticipated disturbance events such drought, fire, or insect outbreaks fall within the ability of the various ecosystems to absorb and thereby maintain their biological integrity. The Piñon-Juniper Initiative recognized the unique uses, products, and benefits of our piñon-juniper (P-J) ecosystems and is an effort to restore the health and productivity of our P-J ecosystems with management that is sensitive to lifestyle as well as ecosystem needs.

Monitoring and evaluation is another emphasis area. In addition to our traditional monitoring of the implementation of projects, we will need to identify elements needed to actually monitor ecosystems, and to monitor the achievement of our desired future conditions (DFC's), as well as the suitability of chosen DFC's as a portrayal of ecosystem sustainability. A task team on monitoring and evaluation has been established and will be providing guidance on the practical and reasonable expectations of monitoring, environmental analysis, techniques, sampling, documentation, budgeting, as well as serving as a hot line to the Forests and Districts. It is tempting to wait until we have "all" the information we need, but there will always be new research and new technology just around the corner. Rather than be paralyzed into inaction, we plan to implement ecosystem management by taking small steps, and then through monitoring and evaluation, re-evaluated and redirect our management.

Before we can effectively evaluate ecosystems at multiple spatial and temporal scales, we need to have the data in place and the analytical tools available to support ecosystem management. Integration of our inventories, classification, and data base systems are needed to provide a uniform framework for use in land and resource management planning and to develop an ecologically based information system - not only within the Region, but at the National level as well. Immediate needs in our Region are to complete our Terrestrial Ecosystem Survey for all Forest (half of the Forests have been completed so far) and to develop an integrated, uniform, existing vegetation information system across all functional areas. Continued work on a set of Regional standard terms and definitions is another strategy item. Geographic Information Systems (GIS) will be a critical tool to conduct spatial analyses to assist resource managers, and implementation of GIS technology, along with related technologies such as videography and remote sensing, are an important part of our Regional strategy.

To assist in the implementation of the Strategy, an Ecosystem Management Interdisciplinary Team (EM IDT) was chartered this year, with members from the Rocky Mountain Station, Regional resource staffs, the public affairs office, and the program and budget staff. To work on specific ecosystem management topics, task teams have been created. Some of the current task teams are the scientific study team, two teams to work on an integrated existing vegetation data base (a tabular team and a spatial team), a team to explore the data and analysis needed for the human dimension, a team to evaluate demonstration projects, a monitoring and evaluation team, and the Every Species Counts task force that is charting a desired course for threatened, endangered, and sensitive species. Proposals from the task teams are reviewed by the EM IDT. For the first time we have an organized interdisciplinary team of Region and Station employees from all functional areas to review recommendations and coordinate activities across the Region-Station. Right now, the EM IDT is working on developing an action plan focusing on key actions needed to implement the Strategy over the next two to three years.

The concept of taking an ecological approach to multiple-use management is not fully developed and is unevenly understood, both internally and externally. We recognize that the strategy is not a static document, but will continue to grow and evolve over time as more information and experience are acquired regarding the implementation of ecological principles. Rather than trying to fit our strategy to our existing resources, we recognize the need to stretch beyond our resource limitations and invent new ways of achieving our goals. One of the challenges in our continued strategy development will be to provide the necessary guidance to land managers without suppressing the creativity and innovation so critical to the success of ecosystem management. In striving for successful management of our piñon-juniper ecosystems, I have great hopes that this week's symposium will expand our understanding of the social, economic, and environmental aspects of P-J ecosystems and that we will work together in partnership in their management.

Piñon-Juniper Initiative in the Southwestern Region

Douglas W. Shaw[1]

INTRODUCTION

I want to share a little background on the Southwestern Region's piñon-juniper initiative. A little over a year ago, when our Regional Forester was relatively new in this Region, he was approached by several groups and individuals about the need for enhanced management in our piñon-juniper woodlands (P-J). The emphasis placed by these people was the watershed condition in the P-J. The need to improve watershed conditions was also noted in our 1991 Stewardship Review Report and was an expressed concern of many of the Region's line officers. As a result of these concerns, our Regional Forester selected P-J woodland management as one of his two resource initiatives. The other resource initiative is forest health, which focuses more on fuel loading and insect and disease conditions at the urban interface; stand densities in the pine, mixed conifer, and woodland types; and riparian conditions. So there are some mutual concerns shared by these two initiatives, and they will be coordinated in an ecosystem management context.

PROBLEM ASSESSMENT

Because of the watershed nature of this initiative, the lead coordination role was assigned to the Region's Director for Watershed and Air Management. To better address the variety of P-J issues and concerns around the Region, an assessment team was chartered for each state. Each team was led by a Forest Supervisor and included at least one District Ranger and the resource people required to accomplish the assessment. The teams were also charged to define a desired condition, estimate costs and potential accomplishments for a five-year program, and identify potential partners. All this was to be accomplished in a rather short time.

The Region's Terrestrial Ecosystem Survey (TES) was used to derive an estimate of the P-J acres in the Region. The TES is an ecological inventory in which soils, vegetation, climate, and landform are inventoried and integrated into an ecological map unit. We looked at all the woodland vegetation associations that have piñon and/or juniper as a significant part of the overstory. Based on the TES review, we have about seven million acres of P-J in the Region. This is slightly less than a third of the Region.

Another screen of the TES data was used to estimate the P-J acres in impaired watershed condition. The criteria used for this screen included sheet, rill, and gully erosion, and soil compaction. Based on this screen we estimated there are about 3.5 million acres in impaired or unsatisfactory watershed condition; of these, about 1.9 million acres are in Arizona and 1.5 million in New Mexico. People have many theories for why these acres are in unsatisfactory watershed condition; over-grazing in the early part of the century, control of fire, and climate changes are frequently cited. Realizing that these and other causes and their cumulative effects are all part of the history of the P-J, we didn't focus a lot of time on identifying the cause; rather, we focused more on what we can do to make changes for improvement.

We also realized the potential for change varies between ecosystems or habitat types. Some systems can now be managed for small wood products, some for more grasses, shrubs and forbs, but some have been changed to the extent their former potential for productivity is no longer available. Some soils are changed due to erosion and drying.

WHAT DO THE PROBLEM AREAS LOOK LIKE?

Pictures of typical problem areas include P-J stands with bare and eroding interspaces between the tree canopies. Watershed conditions under the canopies are good, but the vegetation cover and diversity between the trees is less than desirable to meet forest land management plan objectives. As a consequence, sheet and rill erosion are common. Enough soil has moved on some sites that an erosion pavement is exposed, reducing further sheet erosion but accelerating gully erosion.

Down-slope sites frequently include gully erosion that is drying previously grassy bottoms and riparian areas. These grassy bottoms were effective in slowing runoff from the steeper side slopes, but now they have very effective drainage systems that move water rapidly off site with eroded soil.

[1] *USDA Forest Service, Southwestern Region, Albuquerque, NM.*

People have lived in the P-J for thousand of years. They derived much that they needed from the wildlife and vegetation available. Piñon nuts, for example, furnished an important part of their protein and dietary fat. Some early cultures derived spiritual values from the P-J, and their successors still do. As a result of this long history of habitation, there is a high density of cultural resource sites in the P-J. These resources are sometimes damaged by erosion.

We still like to live in the P-J: the climate is good, the landscape is aesthetically pleasing, and the land is suitable for construction and other uses. However, today there are a wide range of values and opinions about the P-J. Some consider the P-J public enemy number one, others have a spiritual tie, while others look to the P-J for social needs like nut picking and fuelwood gathering as family activities that provide home needs and income. All these values must be addressed in our initiative.

THE PROGRAM

A study of research on past and current P-J management practices was completed by the Watershed and Air Staff. We reviewed all the research publications we could find from the past several decades, pulled out important findings and watershed recommendations, and published them in a document titled "Watershed Management Practices for Piñon-Juniper Ecosystems." This document is intended as a reference for Districts planning projects.

Based on our experience with P-J practices and project coordination requirements, the state teams estimated we could implement improved ecosystem management on approximately 70,000 acres per year in the Region. The average cost for this improved management is estimated to be $100 per acre. Thus, to implement and sustain our P-J initiative, we will need a budget of $6.5 to $7 million per year.

What are we trying to achieve with our P-J initiative? The desired future condition for each project must be determined by integrating the biological, physical, cultural, social, and economic needs of each ecosystem. However, at a Regional or programmatic level, we want each desired future condition to include the following criteria: (1) improvement of long-term soil productivity; (2) water quality that meets state standards; (3) a wide range of plant and animal diversity; (4) sustainable ecosystems; (5) recognition of the P-J as a valuable ecosystem for uses, products and values; (6) a visually desirable mosaic of vegetation conditions on the landscape; (7) riparian areas managed for their potential and uniqueness; (8) threatened, endangered and sensitive plant and animal habitats protected; (9) historic and pre-historic cultural values protected; and (10) management that is sensitive to lifestyles as well as ecosystem needs.

WAYS TO REACH A DESIRED FUTURE CONDITION

There are many tools available to help move us toward a desired future condition. Some of these tools are discussed in "Watershed Management Practices for Piñon-Juniper Ecosystems." Each project team must decide which tools are most appropriate and how they should be applied to meet specific objective. All the values held by people for each site must be considered in selecting the appropriate tools and techniques.

An example of one technique is fuelwood harvesting followed by lopping and scattering the slash over bare soil areas. This technique provides several benefits. People are employed, a product is harvested, and a micro-climate is established near the soil that enhances conditions for the establishment of grasses and shrubs. Fire may also be an important tool for initiating change and maintaining desired conditions. However, we need to better understand the trade offs in the form of soil nutrient losses when we use fire.

Projects must integrate management techniques and tools from many resources, including wildlife, range, recreation, cultural resources, timber and engineering. Plans must focus on achieving desired future conditions with products as additional results of that achievement. The way we move toward desired future conditions may be as important to some people as achieving the end result. Thus, some tools may not be acceptable.

PARTNERSHIPS

Potential partners are available in other state and federal natural resource agencies and among interest groups like the Soil and Water Conservation Districts. Grazing permittees and adjacent land owners are also willing partners.

WHAT ARE SOME BENEFITS?

Benefits of our P-J initiative include a visually desirable mosaic of vegetation conditions including diversity of both overstory and understory components; soil, water, and air quality that meets legislative and administrative goals; a wide range of plant and animal diversity; and management that is sensitive to the public's life style needs as well as ecosystem needs. Economic benefits include revenue to local economies from fuelwood, piñon nut, Christmas tree and wilding sales, and increased forage for livestock. Resource benefits include improved wildlife habitat, improved riparian areas, protected archeological sites, and reduced road densities.

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What Kind of Woodland Does the Future Hold?

Ronald M. Lanner[1]

One day, when I was a young lieutenant in the U.S. Army, I went into a workingman's bar in the French industrial city of Thionville for a beer. Pierre Mendès-France was the premier at that time, and his efforts to convert the French into a nation of milk drinkers had seriously eroded his popularity. As I sipped cold beer from a tall glass I noticed a sign on the wall opposite, which roughly translated:

- The wine drinker lives seventy years.
- The milk drinker lives sixty years.
- The choice is yours.

Looking around the room, it was easy to see what choice the off-shift ironworkers had made.

Well, at least those Frenchmen were given a choice--which is more than we have been given when it comes to management of our piñon-juniper woodlands. Instead, during the last forty years or so, the federally administered woodlands have suffered insults both verbal and physical, and we landowners have been the big losers. The verbal insults have come from sawlog foresters, who have looked at the small woodland trees, contemptuously labeled them "non-commercial forest," and turned their management over to range specialists. The range managers, often suffering from a malady I call "dendrophobia"[2] have further insulted the trees by calling them scrub or pygmy conifers--as if they were growing in pots or tin cans--and accusing them, on the basis of scanty evidence, of being invaders, and even of "reinfesting areas from which they have been removed" (Johnsen and Dalen 1990). As a forester, it took me a while to realize that what a forester regarded as a tree species that was successfully regenerating in its natural habitat, a range manager considered an invader. I am stressing the difference in world views held by foresters and range managers because I think it is at the root of the mismanagement of nearly all piñon-juniper woodlands by the USDA-Forest Service, the Bureau of Land Management, and several state wildlife divisions in the intermountain area. I hope things are better here in the Southwest. The difference in views becomes apparent when we ask "what is forest"? and "what is range"? Foresters define forest as a community predominantly of trees attaining some density. Range is defined as land, including forest, that produces forages for livestock (Ford-Robertson 1971). If cattle can find something to eat in a forest, the forest becomes range. If the forest has already been written off as non-commercial by dollar-driven foresters, who are thus happy to turn over the responsibility of its management to the range staff, we should expect that management to reflect the agenda of the range specialist. High on that agenda is the "conversion" of non-commercial pygmy invaders to a full growth of livestock forages. Another name for this process is "deforestation." Conversion sounds much better than deforestation, and so does "chaining," or "cabling." But when a land-clearing operation takes place in a forest, as a subsidy for marginal agriculture, the lyric to that song is "deforestation."

Well, you might ask, is deforestation all that bad? Are we really giving up very much? Don't we get benefits in return? These are valid questions and they deserve answers. Of course we have always, throughout our history, changed the nature of the landscape when it was in our interest to do so, when land needed to be put to a so-called "higher use." But in the context of this discussion those considerations are not relevant. Here we are talking about public lands that are under legal mandate to be managed for multiple benefits, and whose managing agencies must justify their actions in environmental impact statements using scientific criteria and benefit-cost comparisons. The benefits that accrue from deforestation hemmed in by these requirements are paltry indeed. First, there is no real question that tree removal can increase livestock forages (Ffolliott and Clary 1982). And, as the Forest Service has found, "the more successful conversion projects just about break even from a benefit-cost standpoint (Clary et al. 1974)."

Unfortunately many do not, and a recent study in Utah has shown further that Resource Planning Act assumptions of forage production potential were usually overly optimistic compared to actual outcomes (Clary 1989). But forage alone cannot justify wholesale tree removal on multiple-use lands. For a while, increased water yields were claimed, but that did not hold up in the cold light of day (Evans 1988). So the major justification now being put forth is improvement of the watershed. Some of

[1] *Professor, Department of Forest Resources, Utah State University, Logan, Utah; and Editor, Western Journal of Applied Forestry.*

[2] *An exaggerated, usually inexplicable, and illogical fear of engulfment by trees, resulting in cold sweats, and relieved temporarily by applying chains and tractors.*

you may be unaware of the developing dogma among those who would deforest our woodlands that piñon pines are causing accelerated erosion of soil, and that killing the trees will save our soil. That idea was floated in the 1973 chaining EIS for Forest Service lands in Utah (USDA-Forest Service 1973). There was not a shred of evidence offered to support it in 1973, and there is none now. In fact, research funded by BLM (Williams et al. 1969, Gifford et al. 1970, Williams et al. 1972, Gifford 1973a) and by the Forest Service (Heede 1987, 1988, 1990a, 1990b) refutes this notion, but the agencies never cite it. Heede (1990a) for example states: "Observations indicated that a closed canopy, not allowing holes of consequence for direct rainfall onto the ground surface, appears to be one of the main, if not the main, prerequisite for a successful buffer against overland flow and sediment delivery." Yet, frequent repetition of the idea that trees are destroying their environment (West 1984a, 1984b), like some sort of mantra, has seemingly given it an authenticity to land managers across the West.

A few years ago the Forest Service reported "Research at the Intermountain Station in Nevada has demonstrated how pinyon pine and juniper invade shrub and grass communities and eventually dominate the landscape, to the exclusion of valuable forage plants. Our investigations revealed that livestock grazing is not the primary cause of pinyon-juniper expansion" (USDA Forest Service 1988).

Curious, I wrote the Station director (Lanner 1989) asking for citations to the specific publications on which that statement was based. Within a few days he sent me two citations (Lassen 1989). One dealt with the use of sapwood area to estimate piñon pine phytomass (Tausch and Tueller 1989), a simple mensurational relationship. The other compared singleleaf piñon and basin big sagebrush water use patterns (Drivas and Everett 1988), and concluded that piñons appeared to control transpirational losses more efficiently during drought. Nowhere in their discussion or conclusions did any of the authors speculate about a possible connection between their limited findings on water use and the big issues of "landscape domination", or the impacts of livestock grazing. This episode suggests to me that even the most neutral factual information about piñon pines is viewed through a lens colored by the prevailing dogma. No wonder the dogma prevails -- one hardly ever hears another side of the story.

A less grand claim in favor of deforestation is that woodland clearing benefits wildlife, but since what is good for some species may be destructive for others, this claim depends on who you like and who you don't like, and is thus subject to endless manipulation. Thus animals that can be converted into dollars, like deer and elk, are given priority by land managers over large predators like cougars and bears, even though the latter may be few in number.

What do we lose when woodlands are cleared away? We lose habitat of animals already present, and migrant birds who depend on this vegetation in spring and fall (Balda 1987). We lose climatic moderation, because woodland reduces wind speed by a factor of three (Gifford 1973b), cools the summers, and warms the winters. These are well-established effects of forest cover, and they are especially attractive when we are hearing of global warming. We lose our history. Clearing of woodland is a notorious destroyer of the artifacts and archaeological sites that are so densely concentrated in the woodlands (De Bloois et al. 1975). Long tree-ring records are lost in the destruction of old trees, a common denominator of most chaining and cabling operations, despite the claims that only young invaders are being uprooted. We lose the value of the trees in sequestering carbon; and if they are burned, the large pools of nitrogen that they contain (Debano and Klopatek 1987). We lose the sustainability of animal populations whose woodland range becomes ever more fragmented and impacted by livestock improvements. We lose the naturalness of our landscape as clearings proliferate like measles on a child's clear skin. We lose the microhabitat diversity that harbors rare plants and animals, as machines reduce the woodland to a vast homogeneous scar. For example, we lose woody plants, important to wildlife, that are concentrated in the half-shade beneath tree crowns (Armentrout and Pieper 1988).

We also lose an inordinate number of dollars. The deforestation of woodland in which the trees are established by bird-dispersed seeds cannot be permanent. The birds always come back, and it is just a matter of time before the new tree population must be dealt with. With limited budgets choices must be made, because re-treatment of all deforested areas is impractical.

Sadly, we lose the public's confidence. The flimsy arguments that have often been made to support deforestation have not played well to the public. The stubborn insistence by some land managers that deforestation saves soil puts them at odds with both common sense and the findings of their own agencies' research. Their lack of credibility erodes the professional capital the rest of us in resource management have worked hard to build up.

We lose the potential of producing useful wood products in moderation: fence posts, fuelwood, charcoal, Christmas trees. And we lose the capacity to produce that most excellent seed of the piñon pine -- the pine nut or piñon. The piñon is understood here to refer to the seed of *Pinus edulis.* There is no need to preach the values of piñones to New Mexicans, but it is sometimes helpful to summarize common knowledge. For example, the piñon pine depends mainly on Pinyon Jays and Scrub Jays for seed dispersal and seedling establishment in sub-soil caches (Marzluff and Balda 1992). That's because those jays find the piñones highly nutritious. Piñon pine seedlings find those seeds nutritious of course, and so do numerous mammals and several other birds. And we do too. Some years ago I argued that the development of corn-based agriculture among early native Americans in the southwest was facilitated by the availability of piñones, and that the relatively high lysine content of the pine seeds compensated for corn's notorious deficiency in that essential amino acid (Lanner 1981a). Since then, it has been learned that the Western Anasazi did indeed subsist on piñones (Sullivan 1992). Actually, all of the nutritive parameters

of P. edulis piñones are impressive -- protein content is about 14 percent; and fats about 62-71 percent. The protein contains all the amino acids, and of the nine amino acids essential to human growth, seven are more concentrated in piñones than in cornmeal. The amino acids tryptophan and cystine are especially abundant. The unsaturated fatty acids oleate, linoleate, and linolenate comprise about 85 percent of total fats. Phosphorus and iron are abundant, and vitamin A, thiamine, riboflavin, and niacin (Lanner 1981a). Other pine nuts have generally similar qualities, with variation in proportions of protein, fat, and carbohydrate; in amino acid profiles; and in fatty acid composition of their lipids (Lanner and Gilbert 1992). But all large pine nuts are known to have been utilized as a foodstuff by people. Thus singleleaf piñon was the staple food of Washoe, Paiutes, and Western Shoshones; the Salish tribes ate whitebark pine nuts; Italian stone pine nuts have long been part of Mediterranean cuisines; Swiss and Italian mountain dwellers ate nuts of cembra pine; and Russians and Siberian tribespeople consumed huge numbers of Siberian stone pine nuts. The nuts of Korean stone pines -- which appear to have found their way into New Mexico lately from China -- are reputed in Korea to have considerable medicinal value (Lanner and Gilbert 1992). And the list could continue. My point is that pine nuts should be taken seriously as food. And not just as a by-product of lands primarily used for running cattle, but as a potential first-line product.

So let us change our customary biases and think about a woodland of piñon and juniper trees managed as a nut orchard. As a first-generation orchard, this one is made up of wild trees that were already established when we began this venture. The orchard is several hundred acres in extent, on flat ground where the soils are deep. Piñon trees here vary in size from seedlings to large full-crowned specimens thirty feet wide and tall. Research done at a new Woodlands Utilization Lab has helped us to come up with optimal spacings that will encourage full crowns that bear large cone crops. The resulting thinnings are sold to firewood dealers. Additional research has located superior producers among the trees, and has come up with a gibberellin spray treatment that greatly enhances the initiation of conelets. Pest researchers have solved the cone moth problems we used to have, and now the great majority of our cones are healthy. Junipers are allowed to persist in the orchard in order to support wildlife that eat their fruits, but occasional thinnings produce salable fence posts. Certain piñon trees in the orchard are off-limits to nut collection in order to retain Piñon Jays and Scrub Jays within the orchard. After all, they planted these trees. When the cones are mature, a crew goes out in a fat-tired pickup truck mounted with steel-tube climbing racks. Climbers scramble up the racks with hand-held cone-pickers that remove the cones and transfer them into a container. The cones are concentrated under a roof where they dry and open. The nuts are removed in a cone tumbler. A fraction of the nuts is put into storage, under conditions determined optimal at the Woodlands Utilization Lab, so that a steady amount can be released to our markets each year, regardless of annual crop size. Our customers must be able to rely on us. The rest we roast, and shell in the newest shelling machine developed at the lab. Our customers are food processors, restaurant chains, supermarkets, manufacturers of cooking oil, and perhaps pharmaceutical firms. We export to Europe and Japan. We who are leasing this particular orchard from the Forest Service or BLM and managing it under their guidance as a Sustained Yield Unit, may even decide to sell to tourists from a roadside stand. We may charge city dwellers to come and pick their own, while staying at the campground. They will pay for that too. We have learned how our crop plants behave, we have done our market research, we are supported by the same kind of scientific research the beef and wood products industries get from the U.S. Department of Agriculture, and we are making money on a healthful and tasty food that -- thanks to the efforts of the Extension Service -- has been incorporated into many recipes and food products now well known to the general public.

Because of the success of these efforts, piñones are no longer regarded as a specialty item for the patrons of the upscale yuppie fern bars we hear so much about when the conversation focuses on specialty food items -- they have been integrated into the American diet, and hardly anybody goes through a year without eating them in pastries, candies, salads, sauces, or as a spread, garnish, or snack. It is even rumored that they will soon equal pecan nuts in production and worldwide sales -- perhaps soon de-throning what had been the only American forest tree domesticated for food production. Starting off with millions of acres of established woodland has given the piñon producers a quick start. This success has also stimulated efforts at genetic selection and breeding, as the Woodlands Utilization Lab broadens its focus.

The benefits of the hundreds of operating orchards are clear to the people of the region. The land is protected, the wildlife sustained, the variety of forest products is expanded, relevant scientific knowledge is developed, recreation is fostered, and people's diets are enriched. Many young people get their first working experiences in the small nurseries where orchard-keepers grow selected seedling stock, or picking cones in the fall, or pasting colorful labels on jars of piñon butter being offered for sale, or doing field work for the biologists who monitor the harvest to make sure enough pine nuts are left for wildlife. At the entrance to the orchard, by the mailbox, there are two western antiques: a weathered wooden wagon wheel, and a ship's anchor chain that weighs ninety pounds per linear foot. The workers understand the wagon wheel, but they can't imagine what an anchor chain would be doing so far from the ocean.

That is surely not the only scenario that one could suggest as a future woodland, but it is one that should be seriously considered. Our efforts to make the woodland what it is not, and to ignore what it can be, have resulted in failures of management (Lanner 1981a, 1981b, 1990). Working against

natural tendencies is costly and often foolish, but it is not inevitable. Just as we can choose between milk and wine, we can choose between management schemes that destroy resources, or that use them intelligently for our economic and social benefit.

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Spiritual Values of the Piñon-Juniper Woodland: A Hopi Perspective

Bruce K. Koyiyumptewa[1]

My talk is not based on any scientific research or technical paper, but is basically a talk from the "heart", management of the piñon-juniper (P-J) woodlands from the heart.

The piñon-juniper woodland plays on essential role in Hopi Indian Ceremonialism. Tribal ceremonies are a significant part of Hopi culture. To the Hopi, spiritual ceremonies is considered to be cyclic, **it does not have a beginning nor an end.**

Before I proceed with my talk, perhaps clarification on the term "Religious Ceremony" or "Spiritual Ceremony" need to be addressed here. Most people unfamiliar with Indian culture often equate the two terms. To me, the two terms are significantly different. I have looked up the two words in the dictionary. Here is what Webster's New World Dictionary said.

RELIGION:

1) A belief in a divine or super human power or powers to be obeyed and worshiped as the creator.

2) Any specific system of beliefs and worship often involving a code of ethic and philosophy.

SPIRITUAL:

1) Of the spirit or soul as distinguished from the body or material matter.

To the Hopi People, ceremonies are spiritual. Spirituality is not a belief in a divine power to be worshiped or obeyed but a belief in a spirit or soul to have a balanced life, to be in harmony with oneself, the Mother Earth, the plants and animals, the universe.

Hopi Spiritual Ceremonies is about having a fulfilled, successful, and balanced life. Here the word "successful" does not mean to be affluent in money or material things but simply to be in harmony with Oneself, with the Mother Earth, Plants and Animals and to have a happy, fulfilled, balanced life.

As indicated earlier, the piñon-juniper woodland plays an essential role in Hopi Ceremonies, "Hopi Thinking", philosophy, if you will is this. "All Things Are Connected, The Earth, Plants, Animals, the Sun, Moon, and Stars, and Mankind. "So-soi-he-he-muh-na-nah-me-wue-yu-wah" is a Hopi Indian word (may be incorrectly spelled) as used here to describe this unique relationship.

Because of this unique relationship, the Hopis emphasize "life values" or "spiritual values" on piñon-juniper woodland resource primarily for their emotional well-being, whereas, the Euro/American philosophy is a linear type of thinking, more of a **profit motive** in management of the piñon-juniper resource.

I think I can relate clearly the significance of piñon-juniper woodland on Hopi spiritual ceremonies by telling a story.

It was sixteen days before the annual Winter Solstice Ceremony", the Soyal Ceremony (re-establishing pattern of life). The elders, the young initiates (Ke-Kelt), and the manfolks were anxious to perform this important ceremony to prepare for the Summer Solstice, or the Niman Kachina Ceremony. The Man Society or "Wu wuchim" Society had just completed the Wu wuchim Ceremony (first ceremony of the Hopi ceremonial cycle). Several young initiates who participated in the first ceremony did not gather adequate ceremonial material from the Tuveh-qulu and Ngomap-qulu (piñon-juniper woodland) the previous year and were quiet concerned. One particular initiate said to his grandfather. "Grandfather", soon it will be time to perform the Soyal Ceremony and I have no more ceremonial material left from the Wuwuchim ceremony to help perform this important ceremony. My God-father and I have taken several trips to the Tuveh and Ngomap-qulu but were unable to find many ceremonial plants, animals, and birds so vital to perform this important spiritual ceremony. Grandfather, you do remember when several men from the Wu-Wuchim Society and young initiates were not successful too. Grandfather, the sand grass (Calamovilfa gigantea) as well as the Tu-cum-seh (larkspur), the Ha-seh (buttercup) and other plants were no longer plentiful. The alder, the hopi-ve-vah (Hopi Tobacco), (Nicotniana trigonophyla) that grow along the wash were not plentiful.

Grandfather, you also will remember the To-cha (Hummingbird), Sikyas-eh (yellow warbler), Keh-lau-yah (sparrowhawk) and other birds no longer stop at the Tuveh-gulu and Ngomap-qulu when they migrate from Mexico and South America because the Pahana (whitemen) at the local Indian agency have destroyed these areas. Grandfather, how can I prepare the Mugh-va-ho (hunter's prayer stick) for my Brothers, the Pahos (prayer sticks) and Prayer Feathers for my mother,

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sisters, uncles, aunts, and people of the pueblo so they can start on their journey, this Road of Life to be in harmony, to have a happy, successful, and balanced life? "Grandson", yes, I do remember, and yes, I will help you with the necessary ceremonial materials, but, you must remember to gather enough but **never, never** take all. You must remember to leave a prayer feather as an offering for all the ceremonial material you have gathered. Grandson, you see, for many years, the local government Indian agency have cleared the Tuveh-qulu and Ngomap-qula (piñon-juniper woodland) to provide forage for livestock. The Indian agency have planted other Tu-sah-kah (grasses, plants), but these strange plants do not provide us material to vital to our spiritual ceremonies. Yes, Grandson, when the ceremonies are completed, and we've gone through the four days of Na-nap-wala (purifying from oneself), **we must carry our message** to the local Indian government agency. The Pahana need to be aware of our concerns.

I think, due to past piñon-juniper management practices (chaining projects) some woodlands are depleted of plants, animals, and birds so vital to Hopi spiritual ceremonies.

The Coconino National Forest recently proposed a draft entitled, "Guide To Native American Use Of Forest Products", which listed various plants used by Hopi Tribal members. I am reluctant to disclose this information to the general public for two reasons:

1. The "New Age" thing is so popular around the Flagstaff and Sedona area that many of these "Wa-na-be" Indians have started utilizing several key plant species that are so vital to Indian ceremonies.

2. In this age of holistic herbal medicinal practices, herbal stores are increasing at an alarming rate. Many of these stores "commercialize" the use of key ceremonial/medicinal plants.

It is my perception that the piñon-juniper woodlands will soon be depleted of these key plants that are so vital to Hopi Spiritual Ceremonies.

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Local and Agency Partnerships in Managing Piñon-Juniper Woodlands

David Lujan[1]

INTRODUCTION

Rural communities in the Southwest have close ties to piñon-juniper woodlands. These ties are economic, social, and spiritual. Because of these ties it is very important for land managers to work with these communities to describe desired conditions for the woodlands. The Tonantzin Land Institute has experience and skills in working with Hispanic and Indian communities that may be useful in implementing a management program in the piñon-juniper.

Tonantzin Land Institute is an advocacy organization whose focus is on the land, water, and human rights of traditional communities in the Southwest. Formed in 1982 by Native American and Chicano representatives, the organization has evolved into the only minority directed and managed program of its kind in the region. It is staffed by five persons and its Board of Directors represent eight different tribal affiliations and three Chicano communities. Approximately fifty traditional communities from Arizona, Utah, New Mexico, and Colorado are actively associated with Tonantzin through the various projects that it sponsors. Our work is financially supported by foundation grants, fund- raising events, and service contracts.

David Lujan is a co-founder of Tonantzin Land Institute and presently serves as its Director. He has developed numerous organizations throughout the country and has worked on several community development projects designed for tribal and Chicano groups in both rural and urban settings. His fifteen years of organizing includes serving as the Legislative Advocate for the five legal services programs in New Mexico and several years of training the staff of farmworker programs throughout the eastern part of the United States.

A training program has been developed by a critical evaluation of Southwestern and National organizing efforts. Over the past ten years, we have collected and developed relevant materials that will be used in training programs. The material can packaged to give grass-root organizations the basic as well as the advanced training needed to effect social change.

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TRAINING METHODOLOGY

The training program starts with the premise that materials and processes should serve the empowerment goals of participants. It begins with thorough understanding of "power" as the basis for learning how to advance the will of our communities. We utilize techniques that show how institutional powers garner information, people, and financial resources--demonstrating clearly how they use these "elements of power" to advance their agendas. We have learned, through painful experience, that we can garner the same elements and move our communities from reactive postures to proactive positions. The training program is separated into three distinct segments; each one corresponding to the natural development of grassroot organizations.

The first phase focuses on the day to day reality that leads to the formation of community groups concerned enough about an issue to do something about it. We refer to this phase as the STRATEGY DEVELOPMENT stage. Training objectives at this stage would include learning how to analyze and choose issues, using direct action, supporting citizen's campaigns, building coalitions and recruiting leaders, developing effective strategies, and generally learning how to deal with short term organizing efforts.

The second phase is termed the ORGANIZATIONAL DEVELOPMENT stage. Unfortunately, many groups jump to this stage prematurely only to find that not everyone in the organization holds the same notions about social change or that the excitement of the issues had worn off and the mundane task of developing an organization just wasn't something they wanted to spend evenings and weekends doing. We use training techniques designed to help the group take a good sense of permanency or "staying power" which is important if the group is serious about creating concrete improvements in people's lives. Critical skills such as holding effective meetings, problem solving, listening skills, writing proposals, and learning how to develop membership plans and carrying our fund-raising campaigns can be provided in this phase. The group "being of one mind", will have a clear vision with measurable goals and objectives and everyone in the core group should willingly share in the workload--no matter how mundane it seems.

It is a long haul for any community group to develop the capacity to move from a position of reacting to issues and concerns to a situation where the group is predetermining what it wants to accomplish. It's a difference of "always putting out brush fires" and truly "taking control of our lives". The phase where we actually take control is referred to as the COMMUNITY DEVELOPMENT stage. As social change advocates, our training program insists upon looking at this phase in a truly holistic manner rather than jumping to the assumption that economic ventures is the answer to our plight. Skills in community-needs assessments, financial analysis, community infrastructure and land use planning, and market analysis can be provided, but not without looking at how bankrupt our spiritual and cultural condition is and not without challenging ourselves to proceed with true alternatives that service the needs of our entire community rather than the aspirations of a handful of so-called "leaders".

It has been our experience that the groups who are aware and accept the fact that organization are living, dynamic creations and that there is a natural process by which they grow that those groups are more likely to be around during the hard times as well as the good times. The trust, the clarity of vision, and the sense of mission will be evident to themselves, their constituencies, as well as their adversaries. "ORGANIZING" works and anybody can acquire the skills to do it effectively and in turn bring about social justice.

Our suggested program for any group would include delivery of three training sessions over the course of three months. Technical assistance consists of telephone and written communication as the need arises. Appropriate reference material is provided at every step to assure that the group is able to monitor and evaluate its own interpretation of how things should be done. The three sessions, each to be covered during two- or three-day training events, can be delineated as follows:

A. **Organizing skills** - A thorough organizational and community assessment is conducted to assure that the group is operating with the same set of assumptions about what needs to be done and to begin formulating ideas about how things should be done. Translating problem and issue areas into strategies and assessing the group's strengths and weaknesses will be an objective of the session. Generally, the group will learn how to analyze, how to plan, and how to evaluate its actions so that what it does with the community is deliberate and not reactive in nature. We will help the group develop specific individual and organizational "actions" that will serve to establish the group's credibility and set the stage for expanding its community of base of support.

B. **Strategic Planning** - This three-day session serves to help the group develop a process by which it determines what and how it wants to do things in the next one- to five-year horizon. Specific techniques will be provided by the trainers then the group develops and implements specific action plans to include a membership plan and a fund-raising plan. Initiation of these critical "road maps" will be monitored closely by the trainers in collaboration with the designated staff and board representatives.

C. **Evaluation and Adjustment** - The final training session serves to take a critical look at the accomplishments of the group during the course of about six months. The performance of specific individuals will be looked at to develop positive ways by which that performance can be improved. A one- to five-year strategy plan will be developed and distributed to demonstrate that the Board is clear and committed to bring about change in the community. The plan will have established financial goals and will recognize the need to continue developing the capabilities of the group as well as of the key leaders.

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The Forest Service's Piñon-Juniper Initiative for the Southwest

Larry Henson[1]

Thanks to Jim Boca, Jeff Kline, and other members of the New Mexico State Land Office for inviting us to join with them in sponsoring this symposium. I am happy to be with you here today. I'm here to demonstrate my interest in healthy productive piñon-juniper ecosystems.

Each acre of land is a treasure to some person or group of people. Every acre is part of a bigger ecosystem and plays a function in the larger system. When any part of the system is not functioning to its natural potential, the whole system is out of balance.

Of course, we are part of this system. As populations grow around the world, we make an ever increasing demand on the land. Although most of modern society lives in cities, we are still tied to the land. Many of us tend to forget these ties. Our fast-paced lives place an increasing demand on the system. Our need for products and other values from the land is increasing as our populations grow. We must keep the basic components of the system — soil, water, air and vegetation — in optimum condition if we are to have a quality environment for future generations.

Public lands, including National Forest lands can and do play an important role in the larger system. These lands help provide for the needs of our generation and keep options open to future generations.

A large percentage of the public lands in the Southwest are in systems that include piñon and juniper trees as a major component of the vegetation. About one-third of the 33 million acres of national forest is in the piñon-juniper ecosystem. People have lived in and near piñon-juniper for thousands of years and the demands grow as our populations grow. Some 3 1/2 million acres, or half of the piñon-juniper in the national forests of the southwest are classified in unsatisfactory soil and watershed condition.

The protection of National Forest watersheds and soils is one of the primary purposes for establishing the national forest system. We must do better at fulfilling this purpose in the piñon-juniper. Although there are many unanswered questions about piñon-juniper ecosystems, we have the necessary knowledge and technology to begin making major improvements.

Much of the piñon-juniper is out of balance, so natural processes such as plant competition, fire, and herbivore use can no longer function as they did before our cultures made heavy demands. These processes functioned to maintain more open tree canopies, vegetative protective soil cover, and animal and plant diversity. Many stands today are dense and highly susceptible to insect and disease attacks.

Along with our historic mission of protecting soils and watersheds, our public is demonstrating a growing interest in improved management in the piñon-juniper. Wildlife and ranching interests in both states want to improve forage conditions in the woodlands. Fuelwood cutters, piñon nut harvesters, and hunters also want better management of the piñon-juniper.

Bringing piñon-juniper ecosystems into balance can help resolve issues such as water quality and availability, competition between wildlife and domestic livestock, biological diversity, riparian condition, and local lifestyle conflicts. We can provide additional products. Opportunities in the piñon-juniper also include enhancing recreation opportunities and protecting archaeological sites.

To redeem our stewardship responsibilities, we are implementing a major initiative to manage the piñon-juniper ecosystems on national forests in this region.

Our desired future conditions for the piñon-juniper will be defined by our social and cultural, economic, and ecosystem needs. Any desired future we describe must include a sustaining healthy ecosystem. Such an ecosystem is characterized by decreased erosion, improved water infiltration into the soil, improved soil organic content, a mix of herbaceous understory, a mosaic of vegetative conditions on the landscape, healthy riparian areas, and a diversity of wildlife species.

We are looking for partners to help us reach the desired future condition. They should provide a broad base of public support and experience for management actions. These partners include the State Land Department's Game and Fish Departments, State Universities, and Soil and Water Conservation Districts.

We must improve piñon-juniper woodland management in the southwest while recognizing the inherent values, including cultural values, of the piñon-juniper ecosystem. Now is the time for innovative ecosystem-based management.

Partnerships are available involving interest groups, research, managers, and educators. We are working to assure that direction, funding, and technology are available to implement our initiative. I'm committed to this initiative and I ask your commitment also. Together, we can make a significant change in soil resources and watersheds that will be appreciated by future generations in the Southwest.

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245 Commercial Leases and Permits for Piñon Nut Harvesting

Jim Norwick[1], Dennis Garcia[2], and Bill Torgersen[3]

STATE LAND OFFICE PHILOSOPHY

Jim Norwick...

There is a greater value to our woodlands than fuelwood or green harvest which destroy the resource base. The State Land Office is doing more than ever to manage its piñon-juniper woodlands through Joint Powers Agreements with the State Forestry Division in areas like Luera Mountain and Black Lakes. That's why we're excited about the possibilities of commercial piñon nut harvest and its relatively benign effects on the resource base.

I'd like to update you on the State Land Office's commercial leasing efforts:

- I have already been approached by several individuals interested in leasing state trust lands for commercial piñon nut harvest.
- Data gathering to assess impacts figure we have over 1 million acres of piñon woodlands. This, however, includes marginal stands of trace and light density which may not be desirable for commercial leasing. When we consider only moderate to heavy density stands the acreage figure drops to several hundred thousand acres.
- Three factors to consider in commercial lease: access, stand density, and cyclical nature of piñon crop.
- State Land Office is responding by generating a commercial lease which would allow an individual the right to commercial harvest. One reason: to keep supplies consistention the marketplace. Where we have two parties interested in the same parcel, rights would be handled like oil and gas leases--under a bid system.
- Traditional users would still be covered under the State Land Office recreational access permit.

MANDATE OF THE NEW MEXICO STATE LAND OFFICE

Dennis Garcia...

- Maximize revenue while protecting the resource
- No free use of state trust lands, must have one of the following:
  - permit
  - lease
  - license
  - or other authorization from the Commissioner
- Generate revenue for beneficiary institutions (public schools, Universities, etc.)
- 9.0 million acres of surface estate (approximately 1 million in piñon/juniper of which we estimate 200,000 acres in heavy to moderate stands (SCS data).
- State trust land in every County of the State except Los Alamos; that is not to say we have P-J stands in every County.

* * *

The USDA Forest Service could issue "Free Use Permits" for picking piñon nuts in the form or an information sheet with tips about how to harvest piñon nuts without harm to the trees. In this way the permit will educate the public and create goodwill and cooperation in protecting the better nut bearing trees from fuelwood poachers.

State Land Office intends to issue commercial leases or easements for harvest of piñon nuts. This is possible because state lands are under the control of grazing leases.

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BUREAU OF LAND MANAGEMENT

Bill Torgersen...

I work with the "Forgotten Forest." The Bureau of Land Management is responsible for 50 million acres of forests mostly located in the western states and Alaska. Of this, 26 million acres are located in the western states, excluding western Oregon, and 24 million acres are considered woodland.

For many years the organizational systems we work within have tended to separate our various professional disciplines. Aren't we really all in the same business? In October 1990, the Director of BLM signed a forest policy which applied to Public Domain which gave the woodland resource the same status and policy guidance as the, as we called them then, productive forest lands. We called this initiative "Forests; Our Growing Legacy." The words "Ecosystem Management" was part of that policy guidance. Policy guidance was put together by an interdisciplinary team. Management direction was strongly influenced by input from a variety of publics.

The management of woodlands resources on BLM land has always been a hard sell. Other Bureau priorities took the limelight and expertise in forest ecology and silviculture suffered. We now have one forester in New Mexico, none in Arizona, two in Nevada, and I think two in Utah. Most of them wear more than one hat. Our appropriated dollars were always tied to board-foot production. We need forest ecology and silviculture expertise in our woodlands and we need it on more than a token basis.

Let's talk about sale and harvest of forest products that aren't measured in board feet. There are several ways this can, and is being done. It can be permitted through free use; however, national policy discourages this. Quite a bit of un-permitted use occurs in the piñon nut harvest in New Mexico. Fuel wood harvest is more tightly controlled. Nuts are sold by short form contract to individuals and/or commercial pickers. Price/lb for piñon nuts is approximately 10% of the selling price which, this year amounted to around $ .20 -.25/lb.

Fiscal Year 1992 sales of piñon nuts:

Nevada	**= 54,440 lbs - $8,904**
New Mexico	**= 100 lbs - $ 20**
Utah	**= 34,245 lbs - $7,828**

Colorado reported a poor crop.

Other Forest Products Sold From BLM Lands

Christmas trees	Wildings
Cactus	Cascara Bark
Moss	Boughs
Cones	Huckleberry Veg.
Fern	Greens
Beachgrass	Manzanita
Burls	Yew Bark
Bear Grass	Seed
Yucca	Joshua
Herbs	
Jojoba	

Total value for other forest products in FY1992 = $286,317

Some creative marketing of forest products has been done. For example, fuelwood in Nevada, which has been harvested and stacked by prison crews, is sold at public auction bringing in excess of $40.00 per cord. In Utah permits were issued by a privately owned store to allow the public the convenience of purchasing permits near the harvest area. In several states commercial and personal use harvest of forest products has been used as a tool for ecosystem restoration. Opportunities here are only beginning to be tapped. We are finding that slash can be effectively used to support establishment of new vegetation on eroded sites and recover plants now absent or nearly absent from the site. Thinning, when carefully done, can maintain productivity of the site, maintain aesthetics, do much to reduce soil loss, and enhance wildlife use.

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Pine Nuts (*Pinus*) Imported Into the United States

Elbert L. Little, Jr.[1]

Abstract — Annual published records of pine nuts (*Pinus*) or pignolias imported into the United States back to 1947 are reviewed here. Most imports, roughly as much as nine-tenths, are shelled. Pignolias imported from southern Europe are Italian stone pine (*Pinus pinea*). In recent years, quantities of shelled pine nuts from eastern Asia have been increasing. The species apparently are Korean pine (*Pinus koraiensis*) and Armand pine (*Pinus armandii*). Now China is the chief source. Competition may become great.

Information on pine nuts of several species (*Pinus* spp.) imported into the United States is important in showing competition with native piñon nuts. For about a century, pine nuts under the Italian name pignolias have been imported into the United States from southern Europe. In recent years, quantities of shelled pine nuts from eastern Asia, mainly China, have been increasing. Competition with piñons in domestic markets may become great. Annual published records by the U.S. Bureau of Census of pine nuts back to 1947 are reviewed here.

The coniferous genus *Pinus* L., pine, one of the world's most valuable timbers, is widespread through north temperate regions and represented by almost 100 species, including about 35 native in the United States and nearly 50 in Mexico. Standard illustrated references for worldwide identification of conifers and their seeds are the revision of Dallimore and Jackson (1967) by Harrison and the new reference by Vidakovic (1991). Geographic distribution of each species has been mapped (Critchfield and Little 1966).

The relatively large seeds or kernels of many pine species have served for human consumption wherever native. Called pine nuts, or pine kernels in England, these seeds mostly with thick shell and a long wing (none innate piñons) that serve in seed disposal, and are borne exposed in cones. Nuts technically are dry hard-shelled fruits of flowering plants. More than 20 species, or one-fifth the total, have been recorded as having edible seeds or nuts. Harrison (1951) cited 18 species (grouping piñons as 1). Passini (1988) reviewed the classification and geographic distribution of 8 species of nut pines (pinos piñoneros in Spanish) of Europe and Asia.

Pignolias imported in quantities into the United States from southern Europe (Portugal, Spain, and Italy) are Italian stone pine, *Pinus pinea* L., which matures its cones in 3 seasons rather than 2. The shells are too thick for cracking with the teeth, as I confirmed recently in a small plantation in Israel. Shelled nuts are long and narrow, slightly larger than native piñons. The Italian common name pignolia (also pinocchio) has remained in use on tariff records for imports of all pine nuts worldwide. In England the term pine kernels is used. Nuts from Syria and Turkey are the same. Nuts from Switzerland may be the native Swiss stone pine, *Pinus cembra* L. Those from United Kingdom apparently were from another country and shelled there.

Imports of unshelled nuts from Mexico, listed in 1953, probably were Mexican piñon, *Pinus cembroides* Zucc. Incidentally, Harrison (1951) observed that nutmeats (endosperm) of that species could be distinguished by their pink color rather than white when raw, becoming grayish when roasted.

About twenty years ago I was surprised to get a phone call from the Tariff Commission about tariffs on pine nuts from China. It was my first knowledge of imports from that country. The year 1976 was the first with imports of shelled pine nuts from China high enough to be listed. Totals increased until China was highest in 1980, 1989, and 1990. In 1989 the total of shelled nuts imported from China was 1,055,816 kg., more than that of native piñon, or twoleaf piñon, *Pinus edulis* Engelm. Competition may become great.

Pignolias imported from Asia are different and should be studied further. The common species in northeastern China and sometimes imported also from Korea is Korean pine, *Pinus*

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koraiensis Sieb. & Zucc. In western and southwestern China, Armand pine, *Pinus armandii* Franch. is common. Imports from Hong Kong obviously originated in nearby mainland China. Pignolias from Taiwan apparently came from the mainland for shelling too. (I visited Taiwan in 1992, where *Pinus armandii* is local in high mountains. Its seeds are not harvested commercially there.)

Publications with summaries of imports of pignolias into the United States cited here were examined in the International Trade Reference Room in the U.S. Department of Commerce building in downtown Washington, D.C. The term pignolia has been used throughout for all pine nuts imported, and scientific names have not been cited.

First, the tariff schedules for 1992 (U.S. International Trade Commission 1992) are have the following low rates of duty:

- Pignolia, in shell, general, 1.5 cents per kilogram (2.2 pounds); special, free; high rate, 5.5 cents per kilogram
- Pignolia, shelled, 2.2 cents per kilogram; special, free; high rate, 11 cents per kilogram.

Annual published records by calendar years beginning in 1947 and continuing through 1988 list separately pignolia in shell and pignolia shelled, totals by pounds and customs value of imports in thousands of U.S. dollars. (U.S. Bureau of the Census 1947-1988). Records of 3 representative years, 1947, 1960, and 1976, are compiled in Table 1. The latest imports beginning in 1989 and continuing through 1991 with totals to kilograms are cited here in Table 2 (U.S. Bureau of the Census 1989-1991).

Table 1. — Pignolia nuts, in shell and shelled, imported into the United States by representative calendar years, 1947 (first record), 1960, and 1976 (first record from China), by countries, totals in pounds and customs values in thousands of dollars.

Pignolia in shell, weights in lb, customs value in thousands of dollars								
	1947			1960			1976	
Country	lb	dollars	Country	lb	dollars	Country	lb	dollars
Italy	3,307	.248	Italy	2,646	1	Total	10,313	.015

Pignolia shelled, weights in lb, customs value in thousands of dollars								
	1947			1960			1976	
Country	lb	dollars	Country	lb	dollars	Country	lb	dollars
Italy	249,755	147	Italy	407,559	365	China	42,491	70
Syria	1,639	1	Korea	2,000	2	Portugal	337,200	768
Total	251,394	148	Portugal	34,719	20	Spain	65,308	152
			Spain	25,725	15	Total	445,499	990
			Total	470,003	401			

Table 2. — Pignolia nuts, in shell and shelled, imported into the United States by calendar years, 1989, 1990, 1991, by countries. Totals in kilograms (1 kg = 2.2 lb.) and customs values in thousands of dollars. Totals from Hong Kong could be combined with China.

Pignolia in shell, weights in kg, customs value in thousands of dollars								
	1989			1990			1991	
Country	kg	dollars	Country	kg	dollars	Country	kg	dollars
China	22,806	56	Total	68,350	78	Portugal	190,240	254
Other	33,831	77				Other	32,590	88
Total	50,637	133				Total	222,830	303

Pignolia shelled, weights in kg, customs value in thousands of dollars								
	1989			1990			1991	
Country	kg	dollars	Country	kg	dollars	Country	kg	dollars
China	1,055,806	5,562	China	638,268	3,983	China	205,092	2,135
Hong Kong	259,827	1.407	Hong Kong	113,867	695	Hong Kong	92,394	1,059
Portugal	98,571	987	Portugal	40,716	450	Portugal	335,931	4,955
Spain	21,576	277	Spain	45,916	447	Spain	178,014	2,322
Switzerland	37,624	209	Other	11,958	94	Turkey	198,522	2,939
Taiwan	14,251	70	Total	850,705	5,671	Other	2,778	44
United King.	11,000	68				Total	1,012,731	13,456
Total	1,449,685	8,585						

Several general observations can be made from these import records. First, the nuts were not designated by scientific name. Further identification is desired, followed by chemical analyses and taste tests to determine preference by the public. It is reported that nuts of a few species have a slightly resinous taste. Roasted nuts of the native southwestern piñon or twoleaf piñon (*Pinus edulis*) have an oily flavor lacking in imports.

Unshelled pine nuts are imported in relatively small quantities. Most imported pine nuts, perhaps as many as nine-tenths, are shelled, for obvious reasons in shipment. The heavy shell adds to bulk and weighs about as much as the nutmeat. Also, labor is available to increase the value of processed nuts, possibly by hand shelling. The seeds of most imported species have relatively thick seed coats and are bulky and heavy. They cannot be cracked with the teeth, like seeds of the two common native piñons. Singleleaf piñon, *Pinus monophylla* Torr. & Frém., of the Great Basin region, has thinner shells than twoleaf piñon, *Pinus edulis* Engelm. of the Southwest Thus, imports of unshelled pine nuts likely will remain low and not competitive with the native thinner-shelled piñon nuts.

In recent years, imports of shelled pine nuts have been increasing in quantities equal to native production. Now the principal source is mainland China, rather than southern Europe. These Chinese nuts produced at lower cost may provide great competition in the future. Other leading countries now are Portugal and Spain. Imports from Italy have decreased.

Shelled nuts are imported in increasing quantities equal to native production. Now the main source is China rather than southern Europe, mostly Portugal and Spain. Imports from Italy have decreased. Competition from China may become great.

Imports certainly are irregular from year to year and from one country to another. Apparently the seed crops of wild trees are irregular, partly because of weather variations. Further comparisons are needed to determine differences in chemical composition of nuts and which taste the consumers like best. It is reported that nuts of a few species have a slightly resinous or turpentine taste. Roasted nuts of the native twoleaf piñon (*Pinus edulis*) have an oily flavor preferred by most persons.

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Four Generations Trading Piñon Nuts With Native Americans: Changes Needed for Future Prosperity

Ellis Tanner[1] and Don Grieser[2]

INTRODUCTION

Good morning ladies and gentlemen. I'm Ellis Tanner of Ellis Tanner Trading Company in Gallup, New Mexico. I'd like to tell you a little bit about myself and my family just so you'll understand a little better where I am coming from.

THE TANNER FAMILY HISTORY

My great grandfather, Seth Tanner, was a scout for Brigham Young on his journey to the West. After Brigham Young and his followers settled in Salt Lake, my great grandfather was sent down to the Four Corners region to set up small Mormon colonies. He did that for several years each time spending more and more time among the Navajos. During this time Seth set up several trading posts. His first was just below Tuba City up the Little Colorado River from Cameron at a place called Tanner Crossing. The Navajos called him "Shush" which means bear. The Navajos have great respect for the bear and from the stories that are told about Seth, he had great respect for the Navajos. He later moved to Tanner Springs near Wide Ruins, a place now owned by the descendants of Chee Dodge. Piñons weren't traded much back then, but they were an important food source. Seth learned that the Navajos kept stashes of piñons in caves scattered around the area, so they could have easy access to them in their travels. The Navajos knew something we didn't discover till the 1960's; that piñons stored best in cool dry places. My grandfather, Joseph Baldwin Tanner, "Shush Yazh" or "Little Bear" as the Navajos called him, had several trading posts across the reservation. He was an influential turquoise and jewelry dealer and trader from the late 1800's to the early 1940's. Joseph was one of the first traders to buy piñons from the Navajos and sell them to nut companies. A story is told of him showing up near Pie Town south of Quemado in a stake bed dual wheel truck looking for piñons to buy one year. Most people were paying 3 cents a pound while he was offering 5 cents a pound. Joseph was one of the major players in the 1936 piñon crop, when the Navajos harvested about eight million pounds of piñons. That seems to be the year we always go back and compare our harvests with. Joseph sold his piñons to the Syrian nut dealers in New York City and these buyers continued to be the main market for piñons until the 1960's.

My father, Rule Levi Tanner and mother Stella Tanner, traded all across the reservation and established several trading posts, some in the western region of the reservation and one over by Crownpoint. My mother is 86 years old and she says their biggest contribution was their seven boys and one girl; all of us were in the trading business. At one time we all collected at Navajo Shopping Center when it was started early in 1957. J.B. Tanner, my oldest brother, started the Navajo Shopping Center and literally changed the whole trading business. The Navajo Shopping Center was the first place Navajos could come with anything they had — livestock, jewelry, piñons — to sell it for cash and then use their cash to shop like we do today in grocery stores. Before the Navajo Shopping Center, the only way Navajos could buy goods at trading posts was through the barter system. Almost all the stores had "bull pens" where the Navajos would point at what they wanted to buy and the trader would get it for them. The Navajo Shopping Center was the first supermarket-type store for the Navajos.

All of my family, going back four generations, have bought and sold piñon nuts. With all the progress and technology available today, the piñon nut trade hasn't changed much from the time my grandfather was involved in it.

All of you obviously have an interest in the piñon tree simply by your presence here. No matter where your interest lies, be it in the forestry department, fish and game, the ranching business, or dealing in the piñon nut itself, I would like you to sit back and relax and join me in an old family custom. In our family when we didn't understand another fellow, we were always told to go walk in his shoes for a few miles before you arrive at any opinion. My business philosophy has always been: "It has to work for all of us." In anything that is going to last, to grow and prosper, it has to work for everybody involved or it won't last; it won't grow. Right now, the pricing of the piñon nut is only working for the buyers at big nut companies. We need to make it work for the Navajo piñon pickers, and for the traders as well as for the small buyers. We're going to take a walk in

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[2] *Ramah, NM.*

the shoes of the Navajo piñon pickers, in the shoes of the traders, and in the shoes of the piñon buyers so you can see the point of view of each of these groups. Then I'm going to propose a solution to this problem, and show you how we can return the piñon nut to its status as one of the biggest cash crops in New Mexico.

HOW THE PIÑON BUYING SYSTEM HAS WORKED FOR GENERATIONS

As far back as I can remember, and as far back as any stories are told in my family, the buyers at the big nut companies have controlled the price of the piñon nut. And they have done it through a very simple method that continues to work even today.

When there is a bumper crop, as there was this year, the buyers will only buy a month's supply of piñons at the beginning of the harvest season. The price is pretty good, and 100,000 Navajo Indians get busy and start picking piñons to bring in to town to sell. As soon as the buyers see large quantities of piñons coming in to the traders and the buyers have a 30 day supply on hand, they quit buying. The traders have hundreds of Navajo piñon pickers bringing in their piñon nuts and no place to sell them. The traders cannot get financing from banks; banks won't accept piñon nuts as collateral. The buyers know the traders will run out of money and start dropping the price they are paying for the piñon nuts. When the price hits bottom, the buyers come back and start buying up the piñon nuts.

This has several bad effects on the Navajos and the traders. The Navajos feel the traders are cheating them, because every time they come to town to sell their piñons, the price is lower. The traders may lose money if they buy a lot of piñons early in the season when the price is high. As the price drops, fewer piñons get picked and bumper crops stay on the ground. Even in good years, there are never enough piñons picked to keep the market supplied year round simply because there is no financing available to traders so they can stockpile the piñons.

WHAT HAPPENED LAST YEAR

The 1992 piñon season illustrates this perfectly. There was a fantastic crop of piñons this year. Prices for piñons started at $3.00 per pound to the picker and dropped steadily until it reached $1.00 per pound. In fact, many traders like myself, just quit buying piñons. As the price dropped, fewer Navajos went out to pick piñons.

We estimate that 8 to 10 million pounds of piñons were left on the ground due to the control of the price of piñons by the big nut companies. Just last week I had some calls from people wanting to buy piñon nuts, and there are none available. With proper storage and handling, we could sustain the market for piñons year round.

My brother, J.B. Tanner, tells me that since 1956 there have been five or six bumper crops of piñons like the one we had in 1992. He tells me that not one bumper crop has been harvested anywhere near to capacity because the buyers always shut down the market early in the harvest to drive the prices down. Without financing the traders cannot keep the price high enough so the Navajo piñon pickers will keep harvesting the piñons.

In years when piñons are not plentiful, we can hardly get enough piñons to fill local demand and the price is good. In 1991, for example, we paid the Navajo piñon pickers $5.00 per pound and they earned every cent of that because the trees that have nuts are scattered and the Navajos have to work hard just to find them. It is the years of bumper crops that we need to harvest as many of the nuts as possible to get us through the lean years and to keep piñons on the market all year every year.

WHAT DOES THIS DO TO THE PIÑON PICKER?

It's time to take a walk in the shoes of our main commercial piñon nut pickers. By our best estimates, the Navajo Indians pick over 90% of all the commercial piñon nut crop every year.

My Navajo friends tell me that in the Navajo tradition, everything that grows on the earth has a purpose.The piñon nut was given to the Navajos as a food and some older Navajos use it for medicine. In the early days the Navajos would gather the piñon nuts and store them for winter. They used them in the foods they ate and they fed them to their sheep and goats to keep them fat during the winter. My Navajo friends tell me that they are the Diné, the "Earth People." They prefer that name rather than the name given to them by the Spanish. And as the "Earth People," they have a great respect for Mother Earth and everything she produces.

The Navajos pick the piñons with respect and pride like no one else on the face of the earth. Piñons are a gift from Mother Earth, given to the Navajos to keep them alive, to keep them going from generation to generation. In the old days the Navajo people would take a certain amount of the piñons they picked and give them back to the Earth with a prayer and an offering of turquoise so there would be more piñons in the future.

These days the Navajos pick piñons to supplement their income. It's hard work. If you haven't done it yourself, you need to try it for a day. My Navajo friends will tell you that you won't be back the second day. You can't pick piñons standing up or just reach up pick them off the trees. You have to get down on your knees and pick the piñon nuts off of the ground. If you have ever seen Navajos picking piñons, you will believe as I do, that the Navajos pick piñons better than any machine ever will.

Let's say you're a Navajo family who decides to go pick piñons. You know the price is $3.00 per pound, so you load up the family and go out to pick piñons for a week. When you get back to town with a big load of piñons, you find that the price is now $2.00 per pound. You can still make a decent wage at that price, so you sell your piñons and go back out to pick more.

This time when you come back to town, the price is $1.50 per pound; not a good price but you have a lot of piñons and it's extra money for your family so you sell anyway. As you see the price drop, you see your hard work turn to nothing. You are angry at the trader, and you feel he has cheated you. This abundance of piñons, which should be an opportunity for you and your family to earn a decent income, has turned sour. You pick enough piñons for yourself and quit.

WHAT HAPPENS TO THE TRADERS?

Now let's see what it's like to walk in the traders' shoes. The traders start out the piñon season with high hopes. Buyers are lined up for the first piñons that the Navajos will bring in. A fair price is set and the Navajos are excited to get out and bring in the piñon nuts. Both the traders and the Navajos know that the best nuts are those picked in their prime, when the cones have fully opened and the nuts have dropped but they have not been rained or snowed on. These are the nuts the traders want to buy because we have a good product and we guarantee it. The traders need to keep a quality piñon nut on the market to keep their customers happy and coming back for more.

About the time that the harvest is in full swing, the buyers quit buying. The traders try to keep the price up so the Navajos will continue to pick. Also, they already have many pounds of nuts in the warehouses which they paid a good price for. If the price drops, the traders will lose money on the nuts they have on hand. This has happened several times in the last 30 years.

Banks won't lend the traders any money so they can keep buying and keep the price of piñons up. The traders start to run out of money, the price of the piñon nuts drops. They face disappointed, angry and frustrated Navajo piñon pickers who tell the traders they are cheating them. The nut companies come back and start buying again when they think the price has hit bottom. By the time the traders have enough money to start buying piñons again, the harvest is over because Old Man Winter has set in. Another year goes by where thousands and thousands of pounds of piñons rot under the trees.

THE BUYERS

You'll have to put on two different pairs of shoes for the buyers because there are two kinds of buyers: the big nut companies and the small store owners. Surprisingly, the many small buyers collectively buy as many piñons as the few big nut companies. Neither the big buyers nor the small buyers want to buy more than enough for their immediate needs when the piñon harvest starts. From past years they know that there can be a tremendous fluctuation in the price of piñons, and they don't want to buy at too high a price. If they get stuck with expensive piñons, they may lose money on them. This is especially true of the small buyers who fear the big nut companies will drive the price of piñons down as they have in the past.

The big buyers know the traders don't have the financing to keep the price of piñons up, so they stop buying in years of bumper crops to drive the price down. They aren't able to buy as many piñons because fewer get harvested, but they make more money on the piñons they can buy.

The big nut companies buy as many piñons as they can at as low a price as they can. Then, as soon as the first major storm hits and the piñon picking season ends, the nuts they bought for $1.00 to $1.50 a pound jump to $7.00 to $8.00 per pound. This happens year after year.

A SIMPLE SOLUTION THAT'S GOOD FOR EVERYONE

As I said earlier, my business philosophy has always been: "It's got to work for everyone." Everyone has to benefit from a business transaction or the business won't grow and prosper. Our piñon nut industry is not growing and prospering.

You've walked in the shoes of the Navajo picker, of the traders, and of the buyers. You've seen the problems of all three. I believe a guaranteed base price of $2.00 per pound for the picker will solve many of the problems faced by all three groups. Hold the bottom price for piñons at $2.00 per pound and then let the free enterprise system take over from there.

The Navajo piñon picker benefits from knowing that his hard work will be rewarded fairly. At $2.00 per pound he will continue to pick piñons throughout the harvest instead of quitting and letting piñons go to waste. If he knows that the price won't go below $2.00 per pound, he will spend more time picking instead of running into town every day to sell his piñons before the price drops. Pride and dignity can be restored in his gift from Mother Earth.

Traders will benefit from a stable price. If everyone knows the price won't go below $2.00 per pound, and financing is guaranteed at that rate, they can buy through the entire harvest. No longer will traders get stuck with warehouses full of piñons that can't be sold because they paid too much for them. Traders will be able to buy whole bumper crops like we had this year, and keep the piñons on the market year round. When piñons are available year round, then more stores like the big supermarket chains will carry them.

Even the buyers will benefit from knowing that the price won't go below $2.00 per pound. With that price guaranteed, the big buyers won't be able to manipulate the market. The little buyers will buy more piñons throughout the season. The big buyers will have a more stable supply of piñons and can sell them to places that demand a supply all year every year to put them on their shelves. While the big buyers might not make as much per pound of piñons, they will make more because they will be buying and selling many more pounds of piñons each year.

And this base price will be good for everyone. I came to Santa Fe in September and October of 1992 to try to get the state to guarantee a $2.00 per pound base price. But that was like closing the gate after all the cows were already out. State officials worried that guaranteeing a $2.00 per pound base price meant they were liable for $40 million in loans to traders, based on this year's crop of 20 million pounds of piñons. But it wouldn't mean that at all. Once the big and small buyers see the price isn't going any lower than $2.00 per pound, they will buy from the start of the season to fill their needs. The traders will have enough cash flow from selling piñons to keep buying until the peak of the harvest. Financing will be needed during the peak of the harvest when the nut is at its best, so it can be picked, bought, and warehoused before rain or snow ruins it. The state would only have to guarantee a fraction of the potential $40 million (on a 20 million pound harvest) and only in years when there is a bumper crop. During the years when there are fewer piñons, the price always stays above $2.00 per pound. And there are always plenty of buyers so the trader won't need as much financing for as long a period of time.

Will it be good for everyone else? Think of 10 million pounds of piñons that didn't get picked this year. Think of the poverty on the Navajo Reservation. Think of an additional $20 million injected into the economy of the state of New Mexico. You bet it's good for everyone!

And as the market for piñon nuts grows, it can also be good for others. It won't happen overnight, but as the market grows, ranchers may want to keep piñon trees simply because of the revenue they bring in. There may come a time when a rancher will carefully compare the income available from the piñon trees on his land to the income available from more cattle. Ranchers may want to keep some piñon trees so he always has a cash crop available in case the market drops on cattle, so he won't have all his eggs in one basket. With coming technology and machinery being worked on by New Mexico State University, ranchers may soon be able to harvest their own piñon nuts. Forestry and land departments can generate revenue through permits and leases. The potential is there for the piñon nut to once again become a major cash crop for New Mexico.

WILL IT WORK? IT ALREADY HAS!

My oldest brother, J.B. Tanner, thought a stable base price was the key to the piñon nut business 30 years ago. And he decided to prove to the banks that the piñon nut was good collateral. He got five of Gallup's wealthiest businessmen to join him to finance the buying of the piñon harvest at a stable price. They all had to sign notes with the banks to get enough money. J.B. agreed to pay them interest on their loans so that they could make some money on this deal.

So J.B. and another brother Joe started buying piñon nuts. It was a year with a good harvest, not a bumper crop, but there were plenty of piñons. My brother Joe estimated we would buy a quarter of a million pounds, and we ended up buying over three-quarters of a million pounds of piñons. Right on time the big nut companies quit buying. J.B. held his price and kept right on buying piñon nuts. Other traders quit buying. The big nut companies waited and waited, but the price didn't come down.

J.B. decided that if the nut companies wouldn't buy, he and Joe would have to sell the piñon nuts themselves. They bought a cleaning machine and put me to work cleaning the piñons. I had three 8 hour crews of 10 men and women running the cleaning machine 24 hours a day. The machine did a great job, and then we picked out all the cracked piñons and anything else the machine missed on a conveyor belt before the piñons were bagged and warehoused.

As the warehouses filled up and the money began to run out, J.B. decided to send Joe to New York City with a semi-load of 40,000 pounds of piñons. Joe decided to sell them himself to all the little grocery stores in the city. Hundreds of phone calls later he developed a market for the piñon nuts and found another food distributor who would handle the nuts in New York. Before he could leave New York City, the nut companies gave in and began buying piñons. Since that time, the nut companies have not been as powerful a force in the marketplace. But they fully intended not to buy one piñon nut and break J.B.

The buyers started buying just in time because the loans at the bank were at their limit. But with the cash flow from selling to the nut companies, we made it through the whole season with a stable price.

By the time J.B. sold all of his piñon nuts and looked at his bottom line, he found that all he had done is proved his point. Paying double interest, to the bank for the loans and to his business partners for using their money, ate up all his profits, but he had proved that a stable base price for piñons works for everyone.

With a cleaner and all the storage problems worked out, J.B. began planning to purchase roasting and packaging equipment. We thought we had proved our case, and we were ready to become a nut packaging company that would have taken the place of some of the big nut companies. But the next year, the banks wouldn't finance the nut company and in fact they wouldn't even loan money with piñons as collateral. So he threw up his hands in frustration and just quit on the piñon business.

CONCLUSION

We've known for 30 years that a stable base price for piñon nuts will work. But we continue to let the nut companies manipulate the price and maintain control over the piñon nut market.

We have to convince the financial institutions that the piñon nut is just like any other agricultural product. We need to harvest the piñon when it is in its prime. Then we can store it and market it. Without a guaranteed base price to our Navajo commercial piñon nut pickers, we can't harvest enough piñon nuts to make the market grow. Can the piñon nut industry work for all of us? Can the piñon nut regain its status as a major

cash crop in New Mexico? Yes, when we guarantee a fair base price to our Navajo piñon nut pickers. It worked 30 years ago; it can work today.

The $2.00 per pound base price is just a beginning. As we expand the market and let the free enterprise system work, I believe there will be a day when piñons command a much greater price. I'll know it's successful when I see ranchers taking as good care of his piñon trees as he does his cattle.

In closing I would like to publicly thank our State Land Commissioner Jim Baca for keeping the door of opportunity open so those of us in the piñon nut industry could get in gear to bring about the changes we need. I know you'll do the same great job at the national level that you did for us here in New Mexico.

ISSUES AND QUESTIONS FOR FURTHER STUDY & RESOLUTION

I. What financing is available for a piñon nut packaging company?
  A. What would we need to do to get SBA or FAA loans?
  B. What role will the state play in getting financing?
  C. Is there state economic development money that could be used for a piñon nut packaging company?
  D. Crucial for piñon nut packaging company to have financing to purchase enough nuts to last the entire season.
  E. Financing to develop and market piñon nut by-products.

II. What will it take for financial institutions to accept the piñon nut as collateral?
  A. What is the best and safest way to handle and store nuts?
    1. What studies have already been done on this?
    2. Forest service people told me they have piñon nuts that have been in storage for 10 years.
    3. Release information on storage techniques.
  B. Bonded warehouse system with 3rd party involvement.
    1. Cleaned, sacked, and ready to be shipped when put in warehouse.
    2. Assurance that if trader goes broke, bank can step in and sell piñon nuts to recover loan.
  C. Marketing plan and market information.
    1. Purchase orders from buyers.

III. Improve communication among agencies (Forest Service, BLM, fish & Game, State Land officials, etc.) who are in the field.
  Let the Piñon Nut Trade Council know:
  A. Where will there by a piñon nut crop?
  B. What is the size of the crop? Scale of 1-10.
  C. Where are there cones -- for the next year's crop?
  D. Have agencies establish a unified permit system:
    1. Easy for pickers to get permits.
    2. Free -- no charge to pickers.
    3. Will promote better care of land by pickers.

IV. Research and statistical data kept and analyzed.
  A. Compile piñon nut crop data for different areas by year:
    1. Spot trends -- what areas have good crops?
    2. Predict place and size of crop for future years.
  B. Compile piñon cone reports by year:
    1. What areas have cones but no piñon nuts?
    2. Why did it happen?
    3. What areas consistently have nuts the year after they have cones?
  C. Compile data on test areas and compare to wild areas:
    1. Pruning techniques -- crop yield.
    2. Use of fertilizer -- crop yield.
    3. Water/irrigation -- crop yield.
  D. Can anything/research be done with piñon nuts on the ground now?

  If there is a valuable research that could be done, I will put up some money to get the piñon nuts picked.
    1. Piñon nut oil, animal feed, cosmetic products like soaps, ancillary product, like incense.
    2. Seedlings.
    3. Find a way to separate rancid/bad piñon nuts from good ones/ a way to tell bad nuts from good ones.

V. Ranchers with grazing leases on BLM, Forest Service and state land:
  A. NMSU gets funds from the state for research on piñon nuts and trees:
    1. They have done a nutritional analysis.
    2. Nothing has been done on a shelling machine:
      a. shelling machine is absolutely critical if we are going to compete with Chinese pine nuts and expand the market.
      b. The shelling machine must be a good one -- it must be able to handle a large volume of nuts with minimal breakage.
      c. The Chinese have shelling machines -- get one over here and improve it.
      d. Get a shelling machine in place before September 1, 1993, for next piñon season.
    3. Nothing has been done on a picking machine.
    4. What genetic research and seedling growth research has been done?
    5. What research has been done on storage and packaging methods?
    6. Has a marketing study for piñon nuts been done?
    7. What research has been done on methods to prevent and control disease that threaten piñon trees?
  B. Release all research done to date to Piñon Nut Trade Council.
    1. We need all the information on piñon nuts that is available.
    2. Make sure the state is getting what it is paying for.
    3. Enforce the law.

Revegetation of Piñon-Juniper Woodlands With Native Grasses

Geneva Chong[1]

INTRODUCTION

Much of the Piñon-Juniper (*Pinus edulis and Juniperus monosperma*) woodland at Bandelier National Monument in northcentral New Mexico currently experiences unsustainable, and most likely accelerated rates of erosion (Earth Environmental Consultants, Inc., 1978). The erosion occurs in many areas where herbaceous understory is absent or sparse, which leaves expanses of soil exposed to high intensity rainfall. This paucity of herbaceous groundcover is probably the result of past grazing, fire suppression which allows increased tree density (Barney and Frishknecht 1974) and possibly a drier climate.

In addition to the loss of natural resources due to erosion, the structures and the information contained within the thousands of archaeological sites which Bandelier was created to protect are being destroyed. In a five year survey of 40% of the park over 2000 archaeological sites were recorded and 70% of these were damaged by erosion (Sweetland, Archaeologist, personal communication.) The majority of these Anasazi ruins are unexcavated. Thus, as erosion destroys the chronological layers within them, all their information is lost.

To reduce erosion at Bandelier it is desirable to increase herbaceous groundcover, but this must be done in ways acceptable for use in wilderness areas and around archaeological sites. A better understanding of the ecosystem is also necessary to ensure that revegetation methods will be ecologically acceptable and self-sustaining.

To address the erosion problem I ask two main questions: 1) what determines presence, trends and amount of herbaceous groundcover and 2) what is necessary to re-establish self-maintaining herbaceous groundcover (i.e. native grasses). The goal of my research is to determine the most effective methods for increasing herbaceous groundcover (grasses) to stabilize bare, eroding soil in the PJ woodland at Bandelier. Effectiveness in this case is judged by survivorship and reproduction of native grasses.

The benefits of increased grass cover include: 1) the provision of fuel for wild or prescribed fire which in turn provides for; 2) maintenance of a more open woodland favorable to both grasses and trees (this through the combined actions of fire and herbaceous groundcover which prevent excessive tree seedling establishment) (Burkhardt and Tisdale 1976); 3) protection of the soil from unsustainable rates of erosion; and 4) provision of food for wildlife. As part of this study I hope to gain insight into the factors which control the structure of the ecosystem. In this paper I present results from several supporting (and ongoing) studies designed to characterize the ecosystem and help determine the most effective revegetation methods using tree thinning and native grass seeding treatments.

SUPPORTING STUDIES

Burro Exclosures

Analysis of vegetation data from three sets of burro exclosures that were established in 1975 (Koehler 1974) shows that although there are differences between the three types of exclosures: 1) open to grazers, 2) five strand barbed wire fence to exclude feral burros, cows and elk, and 3) woven wire fence to exclude virtually all grazers (fig. 1), few or no significant overall increases of vegetative cover have occurred (fig. 2) (Potter 1985, Chong 1992, unpublished report). This implies that even with total removal of grazing pressure, 18 years is insufficient time to achieve a significant increase in ground cover and thus a reduction in erosion. With an erosion rate estimated at 0.5m/100yrs, simple protection from grazing is clearly not enough to create and maintain a stable ecosystem.

Vegetation Transects

Permanent vegetation transects (300m each, n=10) are used at Bandelier to describe an area's composition in terms of species' presence and abundance as well as groundcover (i.e. soil, litter, cryptogam, rocks, etc.). Results show that some areas of the park have a surface condition of 50% bare soil with herbaceous vegetation covering only about 10% of the ground. These transects also show that up to 30% of the surface can be covered by microphytic crusts (or cryptogamic crusts) (fig. 3) (Bandelier, unpublished data 1992).

[1] *Student trainee/biological technician conducting research at Bandelier National Monument, Los Alamos, NM and completing an MS in Biology at the University of New Mexico, Albuquerque, NM.*

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Figure 1. — Results of a canonical discriminant analysis (SAS Institute 1988) used to look for differences between grazing exclosure treatments shows that plots are significantly different due to differences in species present (Chong, unpublished report 1992). These differences are not related to amount of herbaceous cover as cover did not necessarily increase with the exclusion of grazing (see also fig. 2). 1=open to grazers, 2=5 wire fence (excludes burros and cows), 3=woven wire fence (all but small mammals excluded). The points' positions on the x-axis are influenced by the presence of five "rare" grasses (possibly sensitive to grazing): *Lycurus phleoides, Aristida purpurea, Sitanion hystrix, Bouteloua eriopoda,* and *B. curtipendula*.

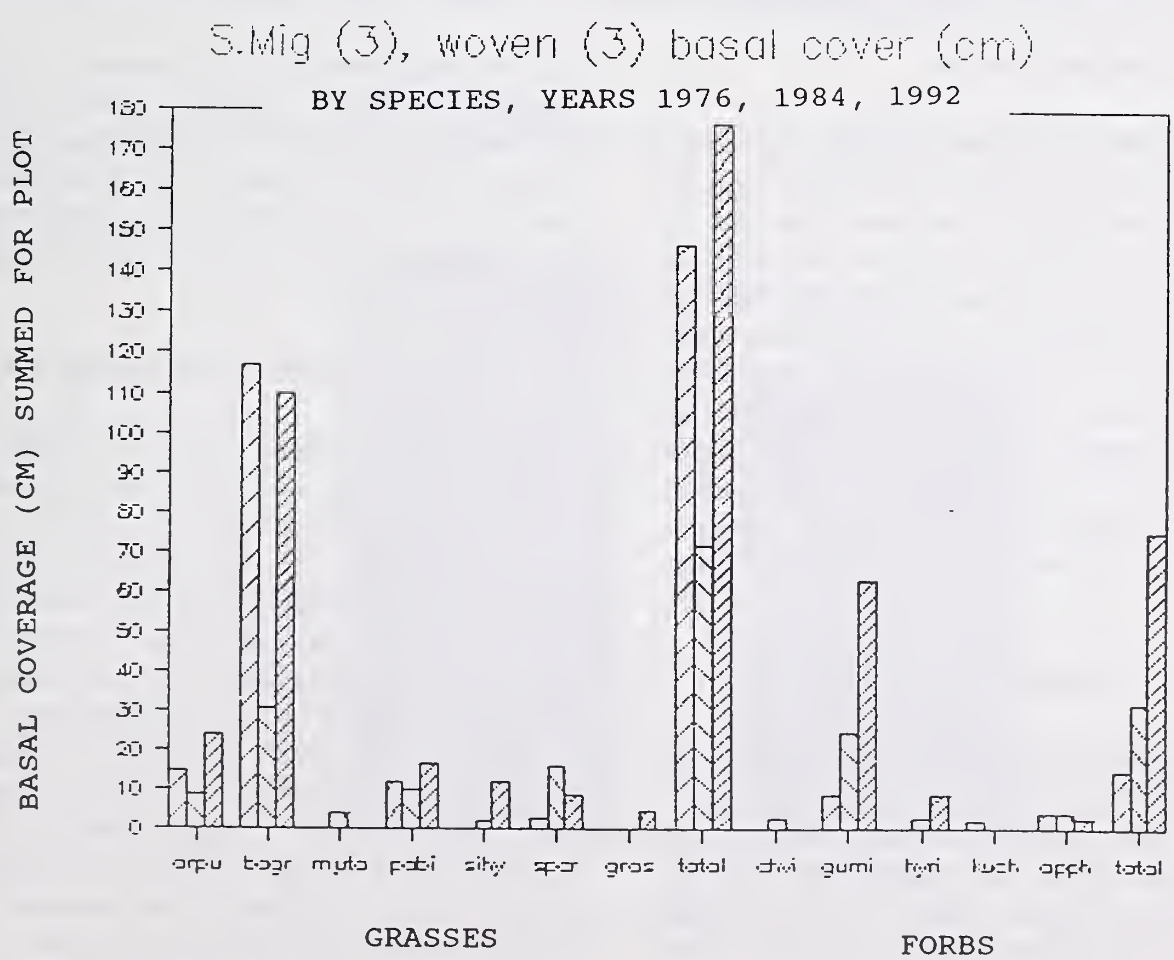

Figure 2. — San Miguel Burro Exclosures: an example which demonstrates changes in herbaceous cover by species over 14 years. There have been no significant increases in grass coverage (arpu, bogr, muta, pobi, sihy, spcr, gras) despite total exclusion of grazers (via a woven wire fence) (Potter 1985; Chong, unpublished report 1992).

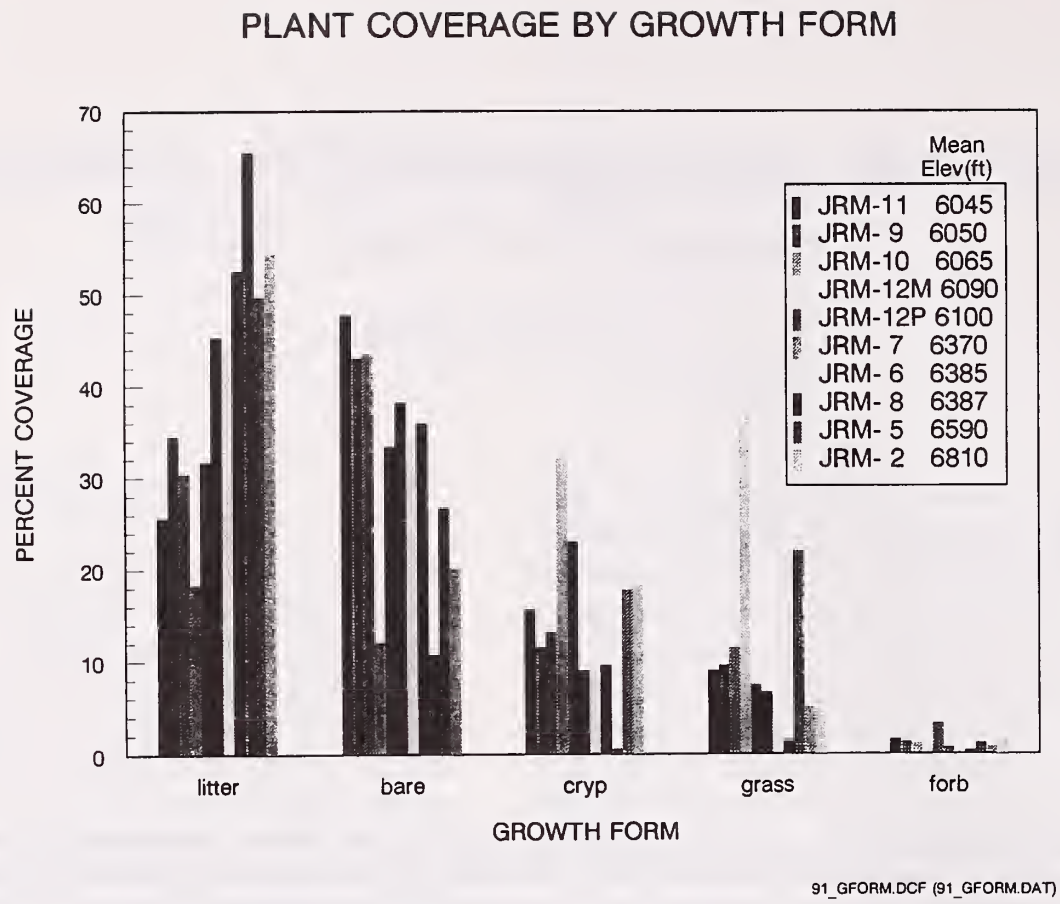

Figure 3. — Results from 10 vegetation transects at Bandelier National Monument show that in some areas of the park bare soil comprises almost 50% of the ground cover while cryptogams may cover over 30% of the soil surface. Grass cover may be as low as 2% (Bandelier National Monument, unpublished data 1991).

Microphytic Crusts

In a greenhouse experiment comparing numbers of seedlings on potting soil, disturbed crust and intact crust I found that there were significantly fewer seedlings on the intact crust (fig. 4) (Chong, unpublished data 1993). This result has negative implications for seed germination in areas of the park with large amounts of cryptogamic crust. However, in the greenhouse seeds that were able to germinate on the crust have outlived those on the other two soil types which is most likely a result of improved moisture statu associated with the crust (see also: Brotherson et al 1983; Lesica and Shelly 1992) Thus a multiplicity of factors may contribute (both positively and negatively) to the spread of herbaceous groundcover in regions with large amounts of crust.

Canopied vs. Interspace Location

Analysis of data collected at the revegetation study site reveals that there is significantly more herbaceous groundcover between (interspace) than beneath (canopied) trees (fig. 5) (Chong, unpublished data 1993). This suggests that trees may be outcompeting herbaceous plants. Possibly of more interest are the results which show that larger trees (assumed to be older as well) have more cover beneath them than do smaller trees, and these differences are statistically significant in the case of *Juniperus monosperma* (fig. 6) (Ibid.). Treering studies show that historically stands of *Pinus ponderosa* which surround my study site experienced a mean fire interval (MFI) of 15.5 years until the late 1800's (Allen 1989). It is likely that the fires spread into the PJ areas of my study site and would have served to kill young trees thus causing the woodland structure to contain more older trees with their associated herbaceous groundcover.

Conclusions from the Supporting Studies

In summary the results of these four studies are: 1) long-term exclusion of grazing does not necessarily result in increased herbaceous groundcover, 2) some areas in the park may have up to 50% bare soil, 10% herbaceous cover and 30% microphytic crust cover, 3) in the greenhouse microphytic crusts inhibit seed germination and 4) tree interspace areas and larger junipers have significantly more herbaceous groundcover associated with them than do canopied areas.

These results indicate that active management may be necessary in order to increase herbaceous groundcover and thus reduce soil erosion in a timely manner in the Piñon-Juniper woodlands of Bandelier National Monument. Management practices such as prescribed burns, prescribed natural fire and control of grazer populations are appropriate, but alone they are not sufficient to increase herbaceous populations since in many areas seed sources are apparently absent. Thus, in the following

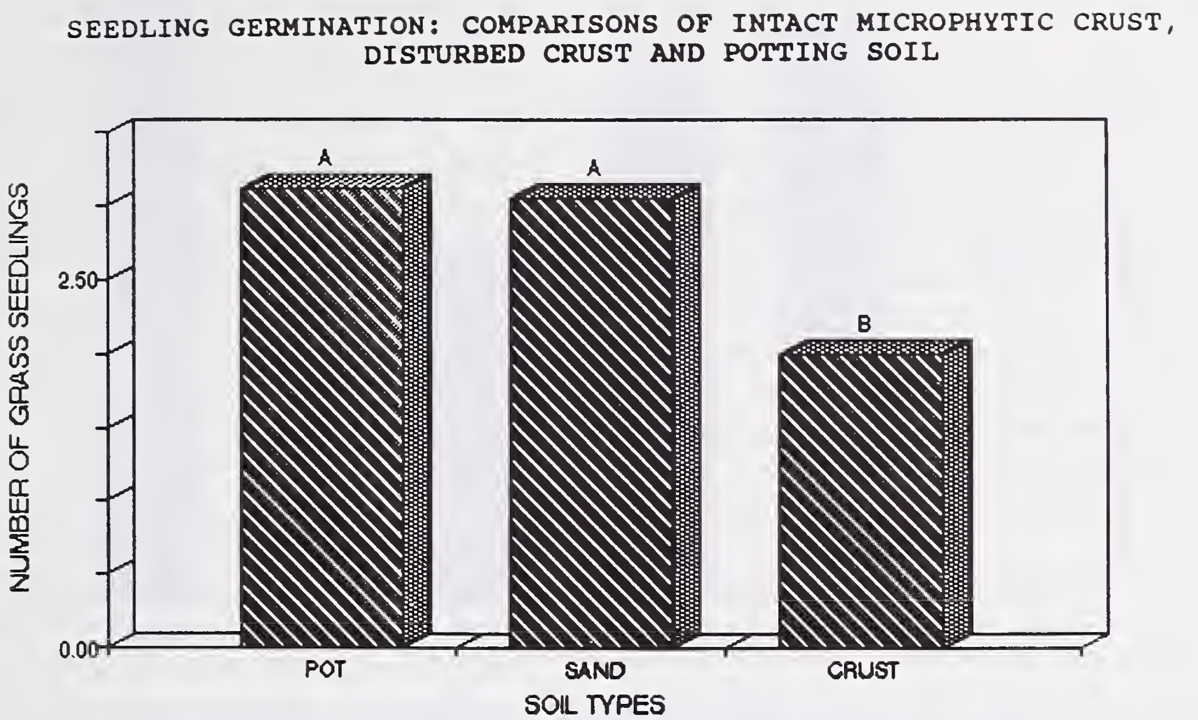

Figure 4. — In a greenhouse study I compared seed germination on potting soil, disturbed cryptogamic (microphytic) crust and intact crust ("pot", "sand" and "crust", respectively). Significantly fewer seeds germinated on the intact crust (statistically significant differences are indicated by having a different letter above the bar.) (Chong, unpublished data 1993).

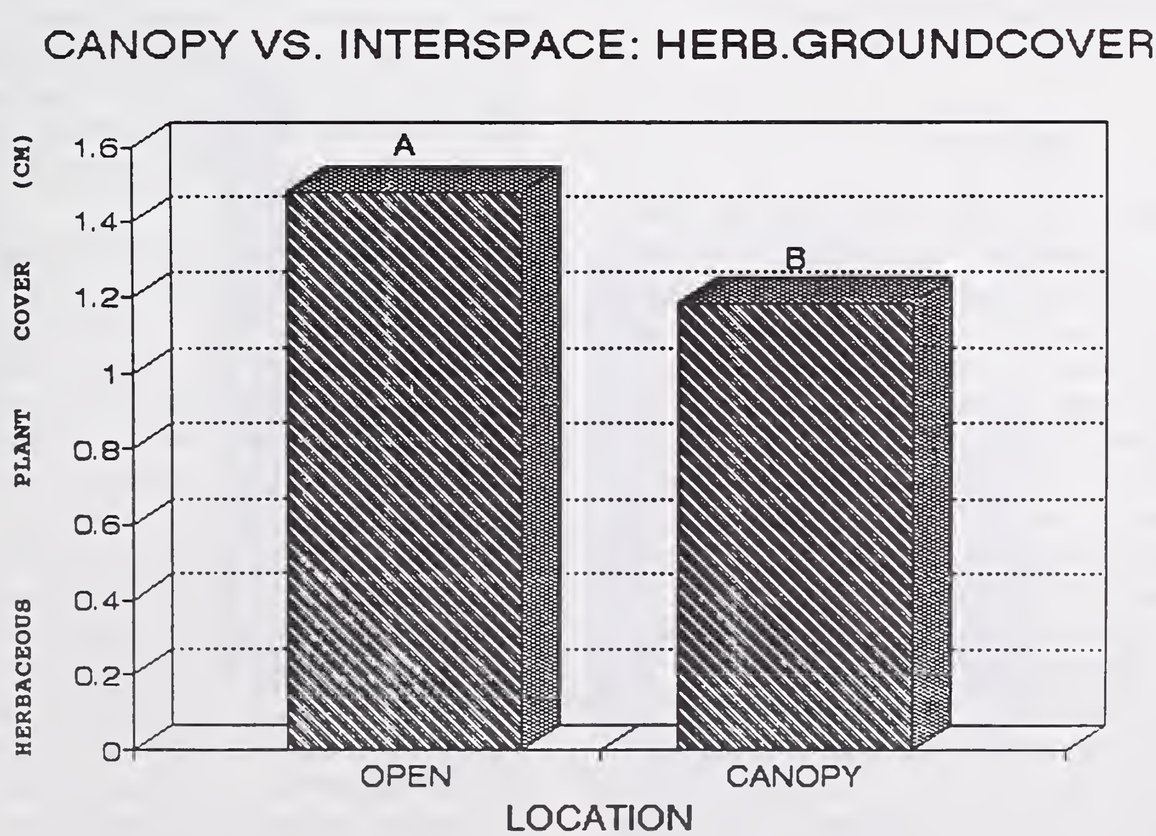

Figure 5. — Areas located in open spaces at my Piñon-Juniper study site have significantly more herbaceous plant cover than do canopied areas (Chong, unpublished data 1993).

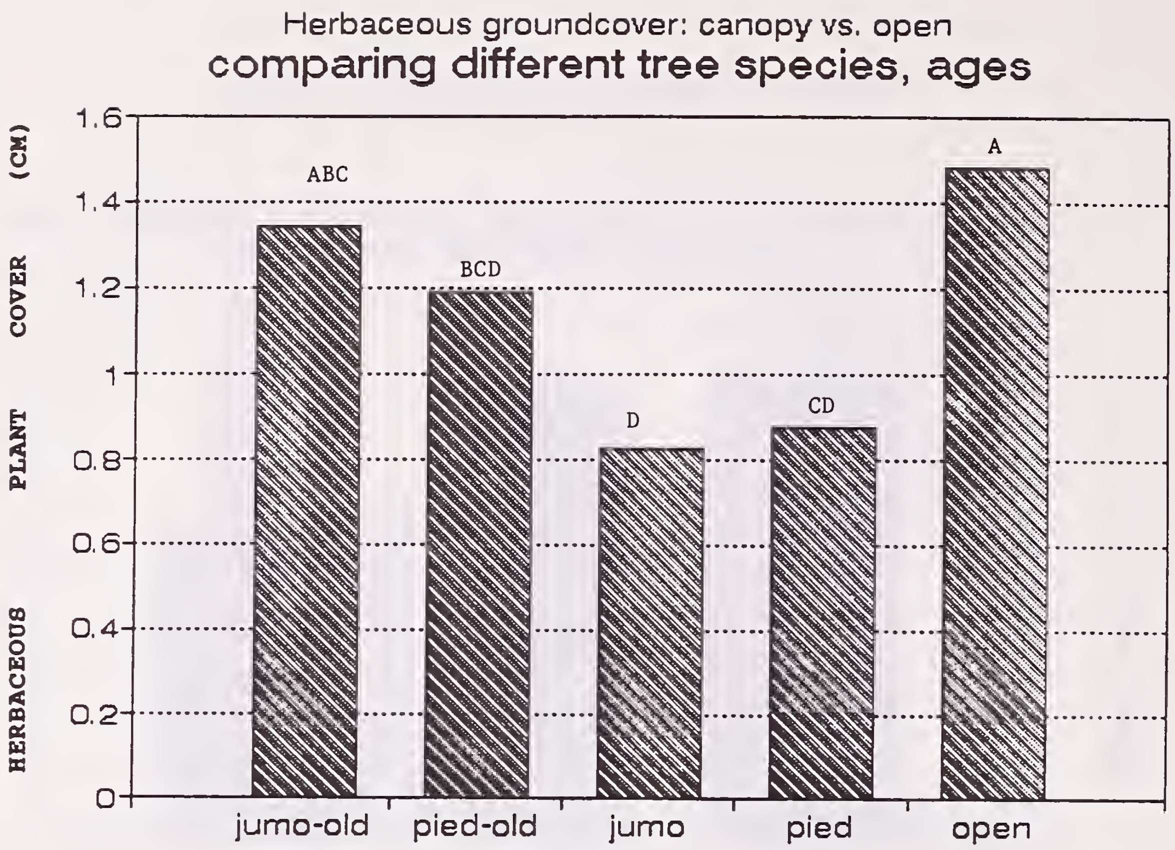

Figure 6. — Larger, "old" trees have more herbaceous groundcover under them than do smaller, "young" trees at my study site. This is statistically significant in the case of *Juniperus monosperma* (jumo) which is statistically equivalent to an open area in terms of herbaceous groundcover (Chong, unpublished data 1993).

sections I address an ongoing experiment designed to determine the most effective methods for increasing native grasses through seeding and tree thinning treatments.

REVEGETATION EXPERIMENT

Methods

To provide resource managers with tested revegetation methods for use in the eroding Piñon-Juniper Woodlands in Bandelier National Monument and other similar ecosystems, a three-year revegetation experiment was begun in March 1991. The objective of this research is to determine the most effective revegetation methods using native grass seed in combination with thinning, mulching and fertilizing treatments. Success is measured by numbers of live grass seedlings. This project is designed to conform to several constraints including: space, funding, and National Park Service requirements (i.e. for use in wilderness areas and on archaeological sites).

In a two way factorial design to look for possible interactive effects between tree thinning and seeding treatments, nine 26 m x 39 m blocks are evenly divided between three tree thinning treatments: 1) thinning with slash left, to act as a mulch; 2) girdling, to leave standing dead trees to simulate the use of pelletized tree herbicide; and 3) no thinning (control). In the thinning process only the smallest trees were removed to achieve 10-15% tree cover and thus simulate the thinning effects of fire.

Within each block 6 plots are randomly allocated to one of 6 seeding treatments: 1) control; 2) disturbance (to determine if a seed bank is present and inducible); 3) addition of seed; 4) seed and mulch; 5) seed and fertilizer, and 6) seed, mulch and fertilizer. The disturbance plots and plots that were seeded were raked to a depth of 5-7 cm with a blade-tined rake. Native grass species used in the seeding treatments are: *Schizachrium scoparium, Bouteloua gracilis, B. curtipendula, Hilaria jamesii* and *Sporobolus cryptandrus.* (Common names are little bluestem, blue grama, sideoats grama, galleta grass and sand dropseed, respectively.)

Each plot contains a grid of 12 permanent monitoring points. Thus each block contains 6 x 12 = 72 monitoring points. Before treatments a 0.9 m x 0.6 m frame was centered over each permanent monitoring point. I photographed the area within the frame and visually estimated the percent groundcover by species. All photographs will be retaken annually and scanned onto compact disks so that vegetative cover can be tracked and compared through time by computer. I mapped the woody vegetation of each plot in detail to provide a record of which points were originally under trees, which points were in canopy interspaces, and which points would remain under trees after thinning. I used this data in an analysis of varaiance to test for the effects of trees on herbaceous groundcover (see the Supporting Study "Canopied vs. Interspace Location"). Thinning treatments were applied between March and May 1992 and seeding occurred in the end of June 1992. Three months after planting, I photographed the sample points within the frame again and counted the number of grass seedlings in situ.

RESULTS

Pretreatment data were used to compare the amount of herbaceous groundcover beneath and between piñon and juniper trees. I used analysis of variance (ANOVA-SAS Institute Inc. 1988) to compare 200 sample points from under trees to 200 points located between trees. There was significantly more vegetation between trees (fig. 5) which indicates that tree thinning may increase revegetation success. A comparison of tree species by size found that there is more vegetation under older (larger) trees (fig. 6). This supports my decision to cut younger (smaller) trees during thinning to simulate the effects of fire on a woodland structure.

Results from an ANOVA on success of revegetation methods after one growing season were obtained by comparing numbers of seedlings for each treatment combination. Despite the pretreatment results which indicated that tree cover may reduce herbaceous groundcover, block treatments (tree thinning) showed few significant differences (fig. 7). However, these results reflect an early stage in the experiment, and the effects of these treatments may become significant over time. For example, grasses in blocks mulched with tree branches (slash) may experience reduced herbivory and benefit from the release of nutrients and organic matter as the wood decomposes. Grasses in either of the thinned treatments (cutting and girdling) may also experience decreased competition for soil moisture. Thus treatment differences due to improved microclimates may become apparent at a later time in the experiment.

Analysis of the plot treatments (seeding, fertilizing and mulching with straw) also resulted in few significant differences after seed application (fig. 8). However, the addition of seed alone was statistically equal to or better than adding seed with other ammendments. The absence of significant numbers of seedlings in the control and disturb plots may indicate the lack of a seed bank and thus the need for seed application. If long term results confirm that seed application alone results in significant numbers of grass seedlings then the solution to increasing herbaceous groundcover may be more simple than expected. It suggests that these Piñon-Juniper ecosystems may recover if given a "jump start" by providing seed (since on-site seed sources may be absent.)

As with the tree thinning treatments, long term survival and reproduction of seedlings may be improved in mulched and/or fertilized plots. The straw mulch may improve soil moisture, organic matter, and nutrient content thus leading to increased growth, survivorship and reproduction of the plants. Fertilizer could have similar effects. However, preliminary results suggest

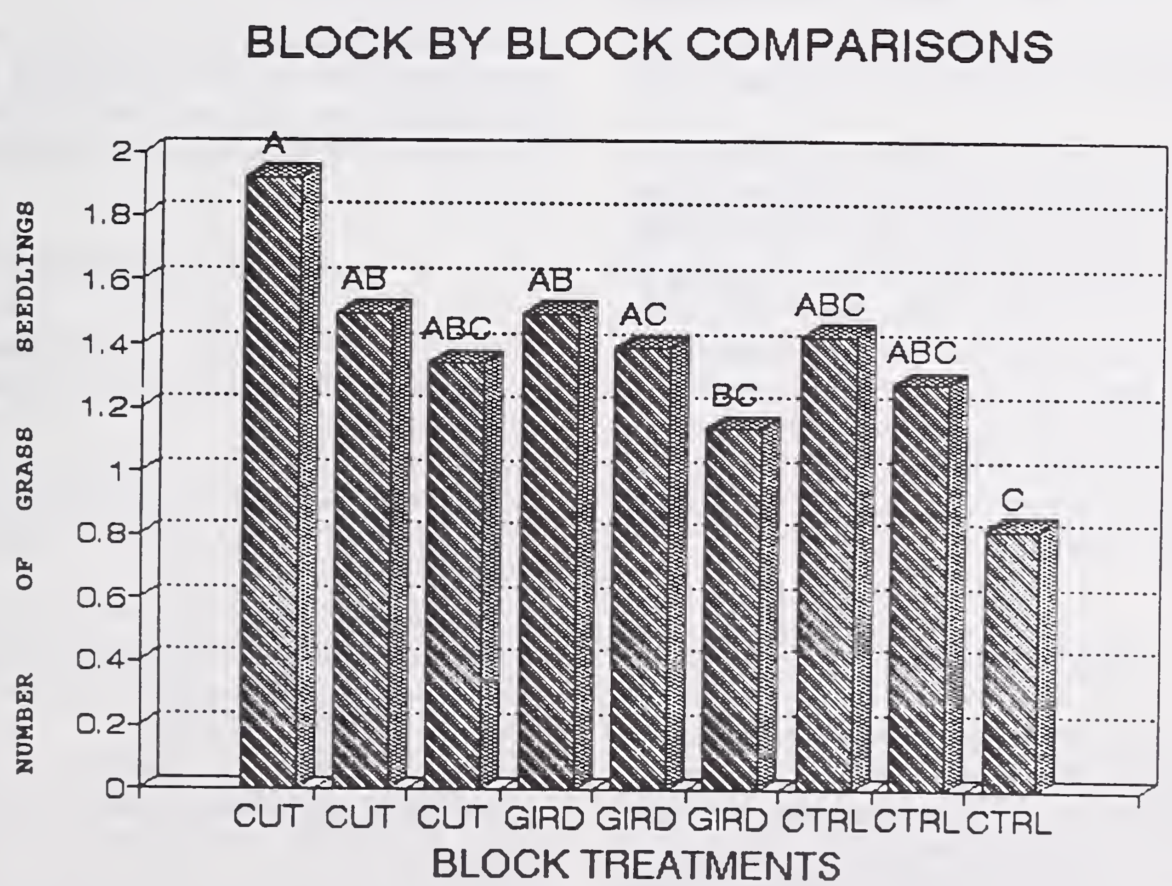

Figure 7. — After one growing season tree thinning (block) treatments show few significant differences. However, the highest number of grass seedlings occurred in a cut block while the fewest were from a control block (Chong, unpublished data 1993). Significant differences may become apparent after the second growing season. "cut"=small trees were cut and the slash was left as a mulch. "gird"=small trees were girdled to leave standing dead. "ctrl"=control where no thinning took place.

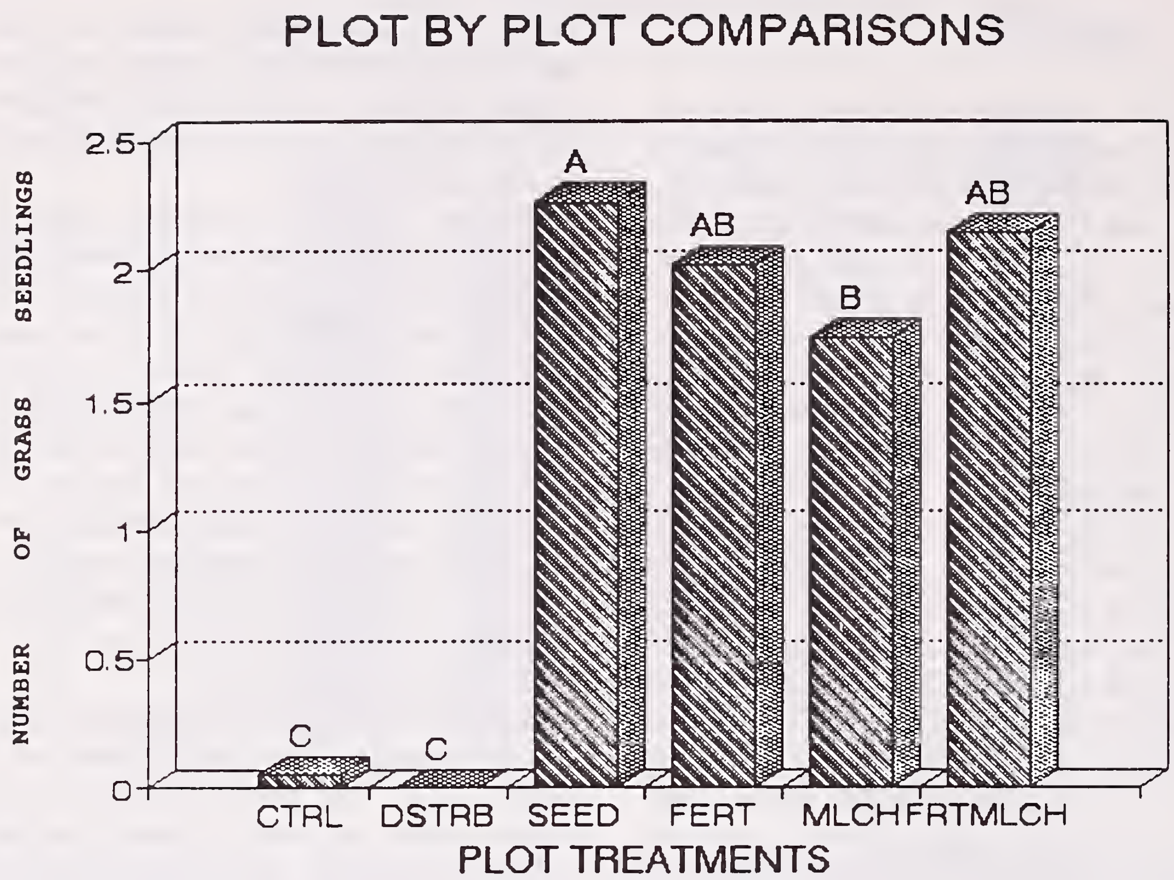

Figure 8. — Between seeding (plot) treatments there were significant differences between adding seed and not which suggests an absent or inactive seed bank and the necessity of adding seed. Adding seed alone is statistically better than or equal to adding seed combined with fertilizer and/or mulch in terms of numbers of grass seedlings. Fertilizer and/or mulch may increase survivorship, however, which could result in significant differences between treatments in the future.

that it does not enhance seedling establishment, and due to the expense this treatment will probably not be repeated in the future.

In summary, treatments that are statistically insignificant after only one, short growing season may produce significant results in future years. This may become more evident as more data sets are collected this spring and fall (1993). In the spring of 1993 I will recount live seedlings. In the fall of 1993 I will photograph the points again, count live seedlings, identify them by species and count seed heads as a measure of reproduction. With this information I will determine survivorship and reproduction related to the different treatments and thus the most successful revegetation method(s) for use in Piñon-Juniper woodlands like those at Bandelier.

CONCLUSION

Recent information gathered on the piñon-juniper woodlands at Bandelier National Monument indicates that active management is necessary to reduce current rates of erosion through an increase in herbaceous groundcover. Reduction of erosion is necessary to preserve cultural and natural resources which the park is mandated to protect. Tree thinning and application of native grass seed may provide one solution for helping the ecosystem return to a more stable and self-sustaining state. Regardless of the actions decided upon, it is imperative that the land manager understands the ecosystem(s) within which he/she works. Without this understanding ten years down the road someone may look out across the landscape and wonder what can be done to mitigate past management.

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Influence of History and Climate on New Mexico Piñon-Juniper Woodlands

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One of the consequences of the development of the theory of vegetational climax has been to guide the observer's mind forwards. Vegetation is interpreted as a stage on the way to something....The important question is do we account most completely for the characteristics of a population by a knowledge of its history or of its destiny? (Harper 1977:628).

INTRODUCTION

In reviewing the population biology of trees, the eminent ecologist John Harper found little support for the idea of stable, steady-state ecosystems (so-called virgin or old-growth forests). Instead, it seemed that disasters were the main determinants of community structure, or at the very least, "bad patches in a sea of favorable conditions, good patches in a sea of bad." (Harper 1977: 269). Nowhere is the imprint of history (and disasters) more evident, and more decipherable, than in New Mexico piñon-juniper woodlands. The history of these woodlands during the past 40,000 years has been synthesized elsewhere (Lanner and Van Devender 1981; Betancourt, 1987; Van Devender 1987; Wells 1987; Van Devender et al. 1987; Betancourt et al. 1990). The present report serves to introduce new perspectives about the influence of history and climate variability on southwestern woodlands and updates research during the last five years. At the heart of this discussion is that climatic variability influences key ecological processes such as masting behavior, recruitment, and mortality to produce vegetation change across a wide range of temporal and spatial scales. We focus not on mean conditions, but on the broadscale effects of rare and extreme events, such as periods of abundant precipitation and droughts. Traces of these extreme events, or the effects of past climate variability, are deeply ingrained in vegetation structure. We feel that this perspective is essential to our understanding and management of the piñon-juniper ecosystem for sustainability and social needs.

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THE LAST GLACIAL-INTERGLACIAL CYCLE

Many of us grew up learning to recite the four glacial phases of the Pleistocene (i. e., the last two million years) identified from the continental geologic record. In North America, they were the Nebraskan, Kansan, Illinoian and Wisconsin phases, punctuated by three interglacials named Aftonian, Yarmouth and Sangamon. The current interglacial, the last 10,000 years, is still called the Holocene. If we learned our lessons well, we also could recall the names of the strath terraces on the north slopes of the Alps that generated the classical sequence of four glaciations in Europe (Gunz, Mindel, Riss and Würm). That has all changed now.

Advances in stable-isotope geochemistry and deep-sea and ice coring have rewritten our textbook knowledge of the ice ages. For example, we know now that the continental record, subject as it is to erosion, underestimates the number of Pleistocene glaciations by at least a factor of four (16-18 cycles vs. the classical four). Oxygen-isotope ratios from foraminifera in marine sediments indicate that long intervals of relatively slow ice growth were followed by short intervals of rapid ice decay, yielding asymmetry in glacial-interglacial cycles. In proportion, warm conditions like today prevailed for only a fraction of the time that continental ice sheets blanketed the high latitudes. The causes of initiations and terminations of each ice age are still being debated, and involve complex phenomena.

The leading paradigm attributes the rhythm of the ice ages to changes in solar insolation caused by periodic variations in the Earth's orbit; this astronomical theory purportedly predicts the timing of the ice ages as reflected in the marine stratigraphic record (Hays et al. 1976; Imbrie et al. 1993a). The paradigm, known as the Milankovitch theory, is now undergoing serious scrutiny (Broecker 1992). The challenge involves oxygen-isotope analysis and mass spectrometer-uranium series dating of a 550,000-yr long vein calcite record at Devils Hole in southern Nevada (Winograd et al. 1992; Ludwig et al. 1992). The Devils Hole record yielded a date of 145,000 for the end of the penultimate ice age, which previously marked the onset of the Sangamon, and is now called Termination II. This date is 17,000 years earlier than the formerly accepted date of

128,000; it casts serious doubt on the exact predictions about the end of the penultimate ice age by the Milankovitch theory (see recent response to this challenge by Imbrie et al. 1993b)

Changes in atmospheric CO_2 and other trace gases (a paleo-greenhouse effect) are another contender for the causes of the ice ages, or at the very least an amplifier of the astronomical forcing (Raynaud et al. 1992). The ice core record shows 40% increases in CO_2 levels from glacial to interglacial phases. Atmospheric CO_2 levels increased from ca. 200 to 280 ppm between 15,000-10,000 years ago. The causes of such large swings in atmospheric CO_2 ultimately involve the largest carbon reservoir, the ocean, and are still being debated. Like the modern global carbon budget, the budget for the most recent deglaciation requires a large unidentified terrestrial CO_2 sink, possibly increased sedimentation of carbon in wetlands, broad floodplains, and coastal settings (oxydation is stifled in waterlogged sediments, enhancing long-term carbon storage). Plant physiologists and paleoecologists now recognize that such large fluctuations in atmospheric CO_2 underlie at least some of the ecological, if not evolutionary, changes traditionally credited to shifting temperature and precipitation regimes (Polley et al. 1992). A better understanding of ecological changes during the last deglaciation, when a 40% increase in CO_2 was accompanied by a 3-5°C global warming, could improve our ability to predict vegetation shifts caused by doubled CO_2 concentrations and a potential 3-5°C rise in global temperatures by the middle of the 21st century. Some might question the utility of such knowledge, mainly because the distant past and the near future will seemingly involve different rates of change (thousands of years on the one hand, decades on the other).

Exactly how quick were the transitions from glacial to interglacial? The last deglaciation consisted of several abrupt jumps and reversals. The most extraordinary of these events was the Younger Dryas, a 1300-year long cold snap (11,200-10,000 radiocarbon years B.P.) named for the reappearance of the polar wildflower *Dryas octopetala* in Europe. In the Greenland ice core record, this cold snap is terminated rather abruptly (1-3 years) by a warmer, wetter climate that doubled snow accumulation rates (Taylor et al. 1993).

The Younger Dryas climatic reversal is attributed to abrupt shifts in the thermohaline circulation of the North Atlantic. A conveyor belt of currents, including the Gulf Stream, carry heat and salt from low to high latitudes where the dense, salty surface waters sink and return south at depth; convective sinking maintains the meridional heat transport. The Younger Dryas cold snap has been credited to lowering of saltiness of North Atlantic surface waters though diversion of glacial meltwater from the Mississipi into the St. Lawrence River. Hypothetically, this infusion of meltwater into the North Atlantic shut off the conveyor belt, lowered temperatures, and thus, suppressed melting of the continental ice sheets. Melting resumed with an increase in salinity due to gradual accumulation by a weakened Gulf Stream, or concentration by evaporation (Broecker 1990; Charles and Fairbanks 1992). The most recent test of this hypothesis used high-precision dating of corals from Papua New Guinea to estimate rates of sea-level rise during the last deglaciation (Edwards et al. 1993). Indeed, the Younger Dryas coincides with a reduced rate of sea level rise (reduced melting), as predicted by the meltwater model. An important discrepancy, however, is that the cold snap continued several hundred years after the conveyor belt started up again. A byproduct of the sea-level studies is that comparison of ^{14}C and mass spectrometer $^{234}U/^{230}Th$ ages of New Guinea and Barbados corals have forced a reevaluation of the ^{14}C-dating method (see legend for fig. 4; note that ^{14}C ages reported in this paper are uncorrected).

Evidence for the Younger Dryas in areas other than Europe has always been controversial (e.g. Peteet et al., 1990), although much anticipated given the global teleconnections in today's climate. This evidence is critical because it might demonstrate the potential for dramatic shifts in regional climates on time scales from years to decades. In the western U.S., much of the evidence revolves around lake level fluctuations in large pluvial lakes now occupied by dry playas or saline lakes. During deglaciation, lake levels fluctuated considerably at Lakes Bonneville and Lahontan in the Great Basin (Benson et al. 1992), Searles in the Mojave Desert (Phillips et al. 1992), and San Agustin (Markgraf et al. 1986; Phillips et al. 1992) and Estancia (Allen and Anderson 1992; 1993) in New Mexico (fig. 1). Retreat of full-glacial high-lake stands began at ca. 13,000 yr. B.P.; a temporary low was reached between 12,000 and 11,000 yr. B.P.; a minor rise coincides with the Younger Dryas between 11,000 and 10,000 yr. B.P.; and the final desiccation at ca. 10,000 marks the beginning of the Holocene. How long did it take lake levels to rise and fall?

Haynes (1991) now argues that the penultimate low lake stands in the western U.S. happened during Clovis time between 11,300-10,900 yr. B.P.; that it coincided with a subcontinental-scale drought; and that, in the San Pedro Valley of southern Arizona, it was followed by a rapid rise in the water table and deposition of an algal mat, known among aficionados as "the black mat," which buried mammoth tracks and Clovis artifacts. Similar sequences occur at other Clovis sites, including Blackwater Draw near the type site of Clovis, New Mexico (fig. 1; Haynes 1991). In short, global phenomena, such as the beginning and the end of the Younger Dryas, may have been manifested in regional changes that were both dramatic and rapid, reflecting rapid reorganizations in climate. Presently, we have few ways of knowing whether the fluctuations in regional water tables, symptomized by the rise and fall of lake levels, the "Clovis drought," or deposition of the "black mat," occurred over years, decades or centuries. If we accept that climate over Greenland switched from one state to another in one to three years, then we should entertain the likelihood that shifts in regional climates were equally swift. Recently, Allen and Anderson (1993) were able to show that millennial-scale oscillations in glaicial lake levels at Lake Estancia occurred as several strong pulses in precipitation that lasted only a few decades and were separated by a few hundred years.

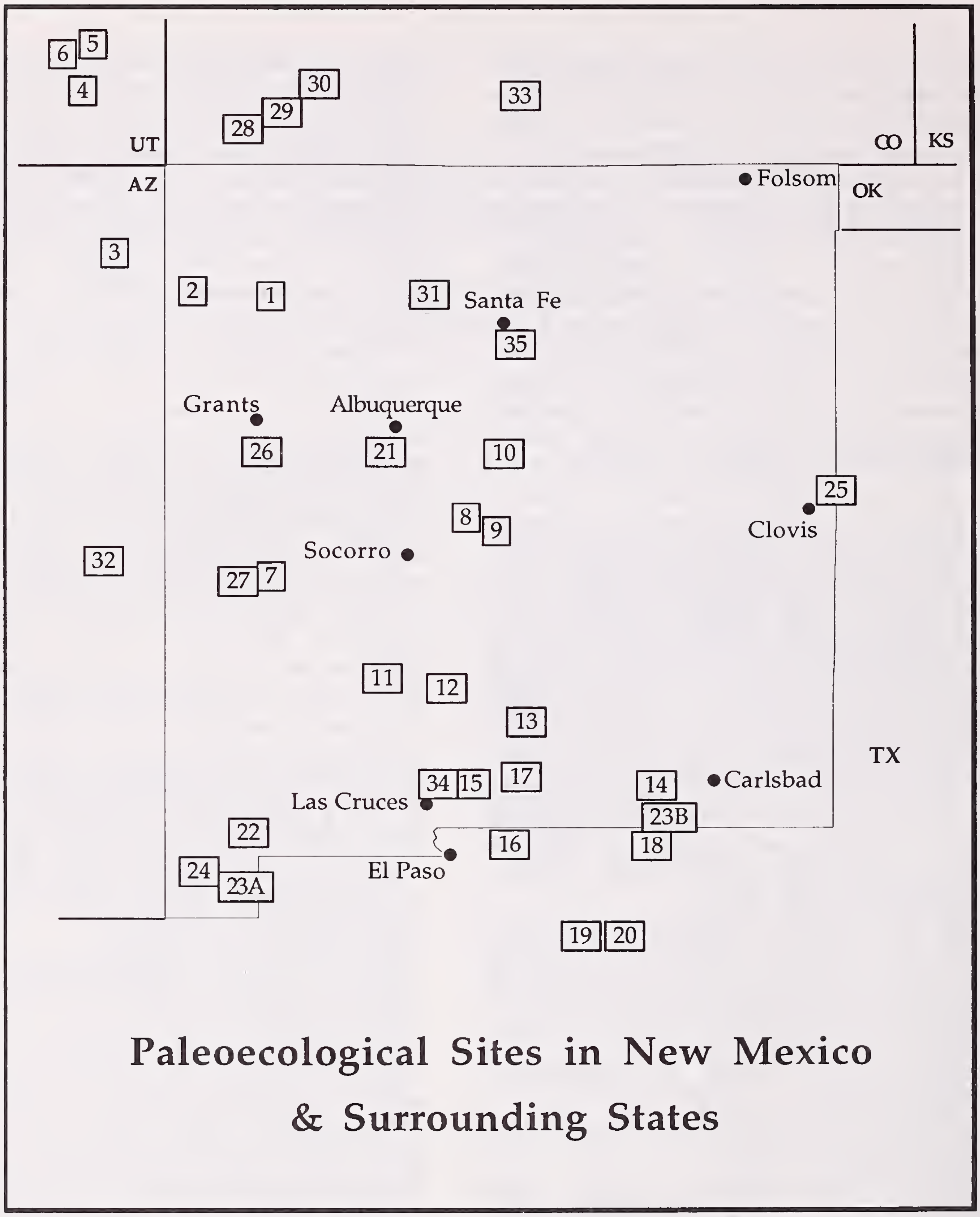

Figure 1. — Key late Quaternary paleoecological sites in New Mexico and adjacent states: (1) Chaco Canyon (Hall 1977; Betancourt & Van Devender 1981; Betancourt et al. 1983); (2) Dead Man Lake, Chuska Mts. (Wright et al. 1973); (3) Canyon de Chelly (Betancourt & Davis 1984; Schmutz et al. 1976); (4) Cottonwood Cave, Fishmouth Cave, Falling Arches (Betancourt 1984; Betancourt 1990); (5) Allen Canyon Cave (ibid); (6) Natural Bridges (Mead et al. 1987); (7) San Agustin Plains (Clisby & Sears 1956; Markgraf et al. 1984; Phillips et al. 1992); (8) Sevilleta LTER (Betancourt et al. in prep); (9) Gran Quivira (Betancourt et al. in prep); (10) Lake Estancia (Leopold 1951; Antevs 1954; Bachhuber 1971, 1989; Bachhuber & McClellan 1977; Brakenridge 1978; Smith & Anderson 1982; Allen 1991; Allen & Anderson 1992, 1993); (11) Fra Cristobal Mts. (Elias 1987; Van Devender 1990); (12) Rhodes Canyon, San Andres Mts. (Van Devender & Toolin 1983); (13) Sacramento Mts. (Van Devender et al. 1984); (14) Rocky Arroyo & Last Chance Canyon, northern Guadalupe Mts. (Van Devender 1980); (15) Bishop's Cap (Van Devender & Everitt 1977); Shelter Cave (Thompson et al. 1980); (16) Hueco Mts. (Van Devender & Riskind; Van Devender et al. 1987; Van Devender 1990); (17) Pendejo Cave, Rough Canyon (MacNeish et al. in press); (18) Williams Cave & C-08, southern Gudalupe Mts. (Van Devender et al. 1979); (19) Quitman Mts. (Van Devender & Wiseman 1977); (20) Steeruwitz Hills (Lanner & Van Devender 1981); (21) Isleta Caves (Harris & Findley 1964); (22) Howell's Ridge Cave (Van Devender & Worthington 1977); (23A) U-Bar Cave; (23B) Dry Cave (Harris 1987); (24) Lake Animas (Fleishhauer & Stone 1982); (25) Blackwater Draw (Haynes 1991); (26) El Malpais (Swetnam & Brown 1992; Grissimo-Meyer in prep.); (27) Bat Cave (Wills 1988; Betancourt unpublished data); (28) Mesa Verde (Martin & Byers 1965; Wycoff 1977); (29) Twin Lakes, La Plata Mts. (Petersen and Mehringer 1976); (30) San Juan Mts: Hurricane Basin (Andrews et al. 1975); Lake Emma (Carrara et al. 1984); Molas Lake & Molas Pass bog (Maher 1961); (31) Alamo Bog, Jemez Mts. (Stearns 1981); 32) Hay Lake, White Mts. (Fine-Jacobs 1985); (33) San Luis Valley (Shafer 1989); (34) Gardner Spring, Organ Mts. (Freeman 1972); (35) Arroyo Hondo (Rose et al. 1981).

Global climatic variability during the last 10,000 years has been equally complex, though this has not deterred paleoecologists and paleoclimatologists from correlating worldwide trends and making generalizations. Like the Younger Dryas, much controversy surrounds worldwide evidence for the Climatic Optimum (8000-4000 yr. B.P.), Neoglacial (4000-2000 yr B.P.), Medieval Warm Period (650-1000 yr B.P. or A.D. 1000-1350), or the Little Ice Age (150-550 years ago or A.D. 1450-1850). For example, the middle Holocene has long been regarded hotter and drier than today in many parts of the world; it's called the Climatic Optimum in Europe, the Hypsithermal in eastern North America, and the Altithermal or "Long Drought" throughout western North America. It is hard to imagine how hot, dry conditions could affect both the Southwest and Pacific Northwest, when modern precipitation and streamflow series in these two areas tend to be negatively correlated (Cayan and Webb 1992). Is climate variability in the 20th century, however, necessarily a blueprint for the last 10,000 years?

EL NIÑO, LA NIÑA, AND THE JET STREAMS:

CLIMATIC VARIABILITY IN THE 20TH CENTURY

A greater mix of storm types and moisture sources affect the Southwest than probably any other region in North America. The annual and decadal frequency of such storms is driven primarily by the mean position and sinuosity of the polar jet stream (an expanded or contracted circumpolar vortex); the strength of the subtropical westerlies; and the mode and variance of the Southern Oscillation (the interannual fluctuation between El Niño and La Niña states in the equatorial Pacific). Thus, year-to-year and decadal changes in New Mexico vegetation are imbedded in global-scale climatologies, and originate from events as far afield as the flip-flop in sea surface pressure fields across the tropical Pacific.

In summer, New Mexico experiences convective thunderstorms, the result of monsoonal circulation, or the onshore low-level water-vapor flux due to the differential heating between the continents and the ocean (Reyes and Cadet 1988; Tang and Reiter 1984). This water vapor originates from both the Gulf of Mexico and the tropical Pacific Ocean and is lifted by high terrain over Mexico and the southwestern U.S. In the Southwest, contributions from the Pacific increase from early (June) to late (August) summer. Variability in monsoonal circulation is influenced by the strength and movement of semipermanent, high pressure cells or anticyclones over the oceans -e.g., the so-called Pacific and Bermuda (or Azores) Highs in the northern oceans. Subsidence along the eastern branches of these high-pressure cells are responsible for the existence of many of the world's deserts, including the Sahara, the Namib, the Atacama, and Sonoran deserts.

The strength of the water vapor flux from the Gulf of Mexico into the Southwest depends on the intensification and westward extension of the Bermuda High in the Atlantic Ocean. Precipitation associated with the Bermuda High is enhanced by a strong high-pressure ridge over the Great Plains, with near-normal or below normal 700-mb heights locally. Summer precipitation is reduced when the ridge develops far to the south over Texas (Sellers 1968). The worst summer droughts of this century (i.e., 1950's; 1988-1989) happened with a "three-wave" pattern of anomalously high 700-mb heights centered over the eastern North Pacific, the southern Great Plains and the central North Atlantic, separated by low centers over the northeastern and southwestern United States (Namias 1955; 1982; 1988). By comparison, the normal moist flow from the South Pacific can be suppressed by northwesterly air flow over northern Mexico. This can happen when the subtropical high-pressure cell in the eastern Pacific Ocean delays its northward migration well into summer. Anomalously warm sea-surface temperatures over the eastern tropical Pacific also can inhibit monsoonal circulation.

Tropical cyclones in both the Gulf of Mexico and the Pacific can influence New Mexico precipitation, mainly during summer and fall. Storms that make landfall between Tampico and Corpus Christi have the greatest effect in southern New Mexico; the moisture can be steered north and inland by the southeasterly flow of summer (Schmidt 1986). Of greater influence is the moisture from dissipating tropical cyclones off the west coast of Mexico, steered into the Southwest by low-pressure systems in late summer and fall. These circumstances can produce regional flooding such as occurred in southern Arizona during fall 1983 (Webb and Betancourt 1992).

Southwestern winter rains originate from large-scale low-pressure systems imbedded in the westerlies, as the Pacific cyclone track moves south in conjunction with seasonal expansion of the Aleutian low-pressure center. During dry winters, the westerlies follow a path around the north side of the Pacific High into the Northwest. In wet winters, this ridge is displaced westward and a semipermanent low-pressure trough develops over the western U.S. Storms then tend to follow the prevailing winds along the west coast, entering the continent as far south as San Francisco. When this happens, the Pacific Northwest is dry and the Southwest is wet. On rare occasions when the Pacific high pressure ridge is well developed, low pressure systems may stagnate (forming cutoff lows) and intensify off the California coast before moving inland into Arizona, where they produce abundant precipitation. As in the winter of 1992-1993, which produced record floods in Arizona, mid-latitude storms can tap tropical Pacific moisture transported by the subtropical jet stream.

Year-to-year variability in southwestern precipitation is linked to coupled ocean-atmosphere interactions involving shifts in the upper-air westerlies and what is now commonly called the ENSO (El Niño-Southern Oscillation) cycle. The Southern Oscillation is the basic ocean-atmosphere rhythm, with oscillatory (aperiodic: 2-10 years) to biennial variations, that dominates interannual climatic variability worldwide (Enfield

1989; Rasmusson et al. 1990; Philander 1990). The main feature of the Southern Oscillation is the remarkably coherent and out-of-phase fluctuations of atmospheric mass between the southeastern Pacific and western Pacific/Indian Oceans. When surface pressure is high in one region, it tends to be low over the other as indicated by the Southern Oscillation Index, or the normalized pressure differences between Papeete, Tahiti and Darwin, Australia. Both the ocean-atmosphere interactions and the teleconnections in global climate are of opposite sign during El Niño vs. La Niña episodes. Associated with the negative or El Niño phase of the SOI (low pressure over Tahiti) are anomalous warming of the central and eastern Pacific; weakening of the easterly tradewinds; convergence of the Intertropical and South Pacific Convergence Zones and a shift of the zone of deep equatorial convection from the area of the Indonesian Low eastward to the date line (over the Line Islands), where tropospheric disturbances (teleconnections) then propagate to extratropical regions.

During the El Niño phase of the Southern Oscillation, warm waters in the eastern Pacific provide the necessary energy for development of troughs along the west coast of North America; the warm waters also weaken the tradewind inversion, resulting in stronger subtropical westerlies. ENSO conditions enhance interaction between tropical and temperate weather systems, and thus, moist, tropical air can penetrate into the southern U.S., particularly in fall, late winter and spring. Although there appears to be no single canonical response in the polar jet stream, the middle-latitude winter storm track is usually displaced southward during El Niño episodes. In general, an expanded circumpolar vortex, with strengthened westerly winds centered about 30°N and positive 700-mb height anomalies at higher latitudes, prevails during decades when the Southern Oscillation approaches a biennial cycle (Cayan and Webb 1992; Webb and Betancourt 1992). In the Southwest, the outcome of El Niño episodes (i.e., 1915, 1919, 1926, 1941; 1958, 1983 and 1993), or decades of frequent El Niño events and an expanded circumpolar vortex (1900-1930 and 1960-1993), is greater precipitation in fall, winter, and spring (Andrade and Sellers 1989; Cayan and Webb 1992; Webb and Betancourt 1992), with slightly reduced rainfall during summer (Sheaffer and Reiter 1985). The opposite is generally true during La Niña events (i. e. 1904, 1917, 1925, 1943, 1950, 1955, 1974, and 1989) or decades when the circumpolar vortex contracts and the Southern Oscillation oscillates at a lower, more irregular frequency (1930-1960) (see discussion and citations in Webb and Betancourt 1992).

Teleconnections with the tropical Pacific have been shown by correlations between indices such as SOI, equatorial sea surface temperatures, and Line Island rainfall against 20th century time series of southwestern U.S. precipitation (Douglas and Englehart 1984; Andrade and Sellers 1989; Cayan and Webb 1992), streamflow (Cayan and Peterson 1989; Cayan and Webb 1992; Webb and Betancourt 1992; Molles and Dahm 1990), and even annual area burned in National Forests of Arizona and New Mexico (fig. 2; Swetnam and Betancourt 1990). In the

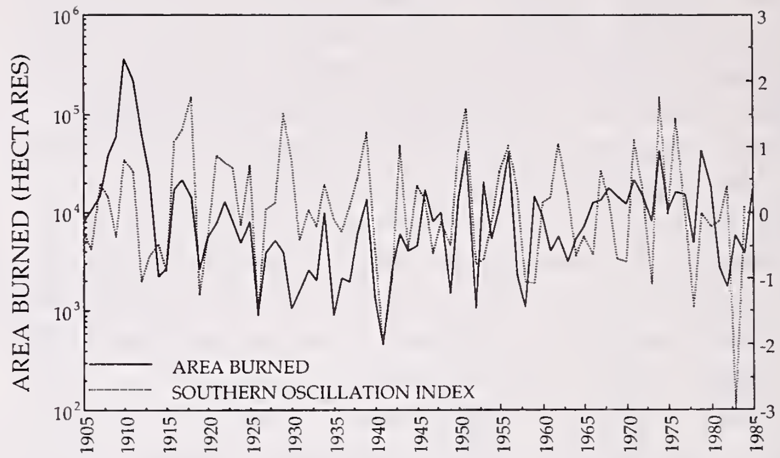

Figure 2. — Comparison of the annual average December-January-February Southern Oscillation Index (SOI) and area burned across all vegetation types, including piñon-juniper woodlands, encompassed in 8 million ha of National Forests in Arizona and New Mexico (Region 3) from 1905-1985. In general, area burned increases during the high or positive (La Niña) phase of the SO, when precipitation is low in the Southwest. Area burned decreases during the low or negative (El Niño) phase of the SO, when precipitation is high (Swetnam and Betancourt 1990). In addition to fire, the SO probably modulates myriad aspects of the piñon-juniper ecosystem, from masting to insect outbreaks.

Southwest, El Niño episodes tend to be the wettest years of record, and La Niña events the driest ones. Teleconnections tend to be lagged, promising some predictive capability a season or more in advance. Lamentably, the correlations are statistically unreliable, with the SOI or Line Island rainfall explaining no more than 25% of the variance in either seasonal or annual precipitation in Arizona and New Mexico. More significant correlations would allow fire managers, for example, to shedule control fires or to improve fire readiness depending on the onset of El Niño or La Niña conditions, respectively (Swetnam and Betancourt 1990).

How did the circumpolar vortex or the Southern Oscillation figure in climate variability on interannual-to-century time scales during the Holocene? Analysis of high-resolution proxy records, mainly tree-rings in the Southwest, enable reconstructions of the SOI during the past 1000 years (D'Arrigo and Jacoby 1991; Lough and Fritts 1985; Lough 1992; Meko 1992). Reconstructions for even longer time periods are currently being developed and extended from ice cores drilled in tropical and subtropical ice sheets (Thompson et al. 1992). Eventually, these records will be integrated to yield a history of SO amplitude and frequency variations back to the last ice age; this assumes, of course, that ENSO is a permanent phenomenon. These records also will be essential in evaluating the role of the SO in future climatic change. Persistence of El Niño-like conditions since 1976 figured prominently in the global warming" of the 1980's (Angell 1990; Ebbesmeyer et al. 1991). Is this persistence, which brought wet weather to the Southwest in the 1980's and early 1990's (with the exception of 1989-1990),

somehow modulated by the greenhouse effect? Historical empirical data about the SO is essential if we consider that general circulation models poorly simulate ocean-atmosphere interactions in the tropics. Future changes in the climate of the Southwest surely will involve both the behavior of the circumpolar vortex and the amplitude and frequency of the Southern Oscillation. And by extension, these changes will drive future variations in the piñon-juniper ecosytem, most likely in the context of extreme weather events.

NEW MEXICO PIÑON-JUNIPER WOODLAND DURING THE LAST 40,000 YEARS

How were New Mexico piñon-juniper woodlands affected by global events like the Clovis drought, the Younger Dryas, or the reduction of El Niño episodes and contracted circumpolar vortex in the middle of this century? Much of what we know about past vegetation in the region has been learned from fossil packrat (*Neotoma* spp.) middens and tree ring studies, complemented by studies of fossil pollen and vertebrate deposits (see sites and references in fig. 1). In the American West, packrats gather plant materials at close range (ca. 100 m at most) and accumulate them in dry caves and crevices; there, the plant debris is cemented into large masses of crystallized urine, which can persevere for tens of thousands of years. Paleoecologists now depend on these deposits to reconstruct shifting distributions of plants and animals in the western U.S. during the last 40,000 years (Betancourt et al. 1990).

The preservation of plant remains in packrat middens is excellent, allowing identification to species and empowering diverse morphological, geochemical, and even genetic analyses. An example of exciting, new applications is analyses of carbon isotope ratios from remains of plants that use the C_4 photosynthetic pathway (e.g. *Atriplex* spp. and warm-season grasses) towards reconstructing the isotopic composition of past atmospheres. These proxy data can be used to constrain competing hypotheses about glacial-interglacial fluctuations in atmospheric CO_2 levels (Marino et al. 1992).

For piñon-juniper woodlands, composed of trees that live half a millennium, the last ice age ended only a few tens of generations ago. The midden record offers some interesting highlights. During the last ice age (40,000-11,000 yr B.P), chaparral and conifer woodlands, including juniper, piñon-juniper, and piñon-juniper oak woodlands, dominated what are now desert elevations (300-1700 m) across the Mojave, Sonoran and Chihuahuan Deserts. Apparently, there was little or no overlap between the glacial and present distributions of these communities, and there were unexpected differences in the dominant taxa. Colorado piñon (*Pinus edulis*) and single-needle piñon (*P. monophylla)*, the dominant species today in the Southwest, had restricted ranges during the last glacial. Conversely, papershell piñon (*P. remota*) and *P. californiarum* subsp. *fallax* (Syn: *P. edulis* var. *fallax*:: see Bailey 1987) were widespread during the glacial contracting to their present relictual distributions during the Holocene (Lanner and Van Devender 1981; Wells 1987; Betancourt 1987). For *P. edulis*, this meant a glacial range limited to Arizona, New Mexico, and far west Texas.

One hypothesis is that lower CO_2 concentrations favored *P. remota* and *P. californiarum* var. *fallax* over *P. edulis* and *P. monophylla*. The four piñon species differ primarily in leaf morphology characters critical to stomatal conductance and carbon fixation- i.e., numbers of stomatal rows and stomatal densities. Studies of fossil leaves (Van Der Burgh et al. 1993; Van de Water et al. 1991) and historical herbarium material (Woodward 1987) show that, over time, stomatal densities are inversely related to past atmospheric CO_2 levels. For piñons, this relation could be tested in a controlled experiment involving the four taxa grown at different partial pressures of CO_2 (see section on Role of Climate in Masting Behavior for alternate hypothesis).

During the glacial, ponderosa pine forests were much reduced or nonexistent across the Southwest, contrary to expectations from a simple lowering of modern vegetation zones with wetter winters and cooler summers. In New Mexico, the only glacial macrofossil record of ponderosa comes from a midden (1705 m) at the northern end of the San Andres Mountains, on the White Sands Missile Range (fig. 1). This midden also contained Douglas fir (*Pseudotsuga menziesii*), blue spruce (*Picea pungens*), and Rocky Mountain juniper (*Juniperus scopulorum*) (Van Devender and Toolin 1983; Van Devender 1990). Only 500 km to the north, in the Four Corners area, ponderosa pine is missing from glacial middens at all elevations (1300-2200 m).

In the Four Corners area, communities dominated by mixed-conifer species occupied similar elevations as piñon-juniper woodlands in southern New Mexico. This point can be clarified by plotting the presence or absence of piñon in glacial middens with elevation and latitude in a transect from west Texas across New Mexico to northern Arizona and southeastern Utah (fig. 3). The northernmost piñon records are at between 35 and 36°N, just north of Flagstaff in Arizona (Cinnamon and Hevly 1988), and 50 km south of Albuquerque in New Mexico (Betancourt, unpublished data). In Figure 3, middens without piñon north of 36° and above 1300 m contain limber pine (*Pinus flexilis*), Douglas fir, white fir (Abies concolor), blue spruce, and Rocky Mountain juniper. By comparison, today *Pinus edulis* reaches the southern boundary of Wyoming at ca. 41°N, where it is replaced by similar mixed-conifer species.

In the eastern Grand Canyon (36°), at ca. 1300 m elevation, Pleistocene communities dominated by limber pine-Douglas fir-Rocky Mountain graded directly into ones dominated by Utah juniper (*Juniperus osteosperma*) in the absence of piñons (Cole 1982). In southern and central New Mexico, the upper range (1500-1700 m) of piñon-juniper woodlands was dominated by piñon growing with Rocky Mountain juniper. Replacement of piñon by limber pine at this same elevational range probably occurred just north of Albuquerque, though we can envision

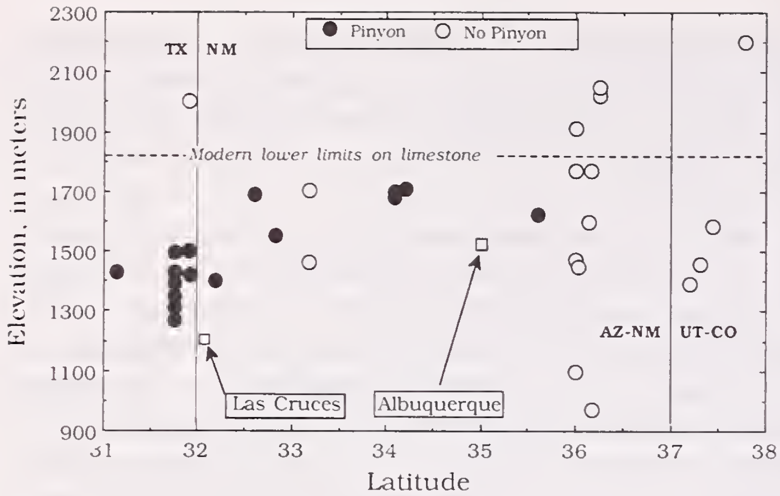

Figure 3. — Latitude-elevation plot of late Wisconsin (20,000-11,000 yr B.P.) middens with or without piñon macrofossils in a transect from the northern Chihuahuan Desert to the Colorado Plateau. Note that the glacial upper limits of piñon coincided with its modern lower limits on limestone. Midden sites used in this plot are located and referenced in Figure 1.

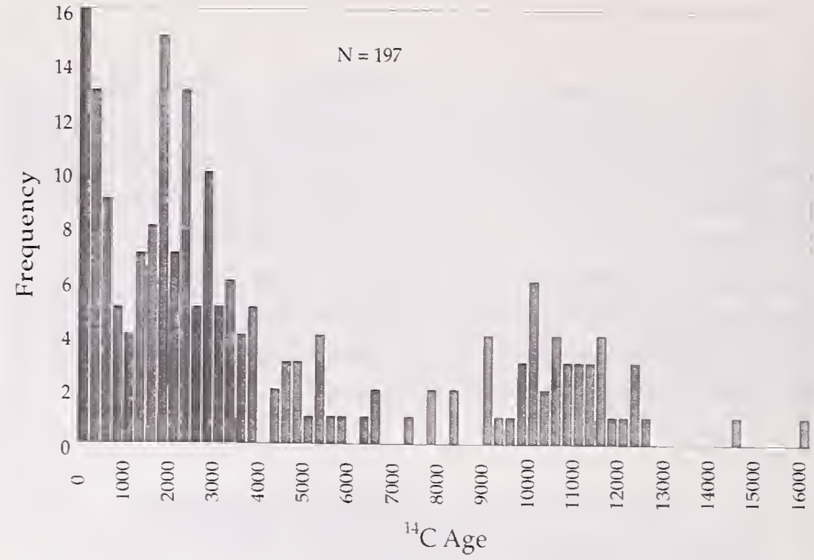

Figure 4. — Histogram of ^{14}C ages from packrat middens in New Mexico, by 250-yr intervals from 0-16,000 yrs B.P. Note the sharp decrease at 750-1250 yr B.P., the wide gap at 6,000-9000 yr B.P., and the secondary peak between 10,000-11,750 yr. B.P. The middle Holocene gap is matched by similar histograms throughout the west, and may denote decreased packrat activity at desert elevations due to diminished cool-season precipitation and lower ecosystem productivity. The peak at the end of the ice age probably reflects greater packrat densities in what was then piñon-juniper woodlands. Note that the reported dates are ^{14}C ages and were not corrected to calendar years using the $^{234}U/^{230}Th$ or dendroclimatic calibrations. Such calibrations, for example, would shift a ^{14}C date of 11,000 yr. B.P. to a true age of 13,150. The error results from secular variations in ^{14}C production due to shifts in the intensity of solar or terrestrial magnetic fields, or to redistribution of carbon isotopes among the various carbon reservoirs. Those of us who rely on ^{14}C dates are now chagrined by the possibility that increased ocean ventilation caused the $^{14}C/^{13}C$ ratio to fall in the latter part and slightly after the Younger Dryas. This would have yielded a 1300-yr (12,300-11,000 calendar age) interval over which ^{14}C ages changed by only 210 years (at ca. 10,000 radiocarbon years) (Edwards et al. 1993). Radiocarbon ages during deglaciation are not only 1,000-2000 years too young, but they may be clustering artificially at a critical time when the climate and vegetation are changing, lake levels are fluctuating, and large herbivores are becoming extinct.

piñon-juniper woodlands as far north as White Rock Canyon, between Los Alamos and Santa Fe on the Rio Grande. Although records are still forthcoming, we can also envision many places in the northern halves of Arizona and New Mexico where piñon, limber pine, and Rocky Mountain juniper might have grown together. A similar gradient occurs today, whereby limber pine in southern Wyoming replaces piñon growing at the same elevations in northern Colorado/northern Utah.

The extirpation of piñon from what are now desert elevations (<1700 m) in southern New Mexico happened at ca. 11,000 yr B.P., coincident with Haynes (1991) Clovis-age drought. Junipers and oaks persisted for another 2000-3000 years at sites ranging from the Big Bend (850-1200 m) in Texas to the Fra Cristobal Mountains (1675-1740 m) in New Mexico (Van Devender 1977; Van Devender 1990). We propose that the extirpation of piñons was caused through broadscale mortality during the Clovis-age drought, and that the climate that followed was sufficiently moist and cool to temporarily fill pluvial lakes, and to maintain and/or reestablish junipers and oaks well below their modern limits. Early Holocene climates, however, were dry enough to prevent reestablishment of piñons, which instead migrated to higher elevations and more northerly latitudes. In the Four Corners area, the period 10,000-8000 yr B.P. supported conifers at lower elevations than they occur today (Betancourt 1990).

Junipers and oaks were extirpated from desert elevations at ca. 8000 yr B.P. Lamentably, the midden record is surprisingly sparse between 8000-4000 yr B.P. (fig. 4). The lack of middens between 8000-4000 yr B.P. could be due to lower productivity, and less packrat activity, during a period dominated by dry winters and hot summers. Van Devender (1990) suggests that summers may have been wetter than today, based on midden evidence. Thus, the middle Holocene hiatus (fig. 4) could be due to higher relative humidities during middle Holocene summers, which would inhibit crystallization of packrat urine (the hardened urine itself is hygroscopic). This is not a far-fetched notion if you consider that urine crystallization and fossil packrat middens do not occur in the semiarid monsoonal areas of central Mexico. There appears to be little consensus about the nature of middle Holocene climates in New Mexico.

The few late Holocene (4000-0 yr B.P.) middens collected at sites in the northern Chihuahuan Desert indicate the upward and northward migration of desert shrubs like creosotebush (*Larrea divaricata*) and ocotillo (*Fouquieria splendens*) (Van Devender 1990). Although not fully documented, we suspect that the extensive stands of these species between 1200-1700 m in the central Rio Grande Basin, as well as along the continental divide in Hidalgo County, New Mexico, have developed only within the last 4000 years. In the area between Socorro and Albuquerque, creosotebush has accelerated its expansion northward and upward during the past century. The northernmost stand of creosotebush along Interstate 25, near Isleta, apparently developed only recently (Van Devender 1990). In the Los Pinos Mountains (Sevilleta National Wildlife Refuge), creosotebush

now grows with piñon on exposed, southerly limestone slopes above 2000 m. Across much of southern and central New Mexico, the range of grasslands has been narrowed by encroachment of junipers on the upper end and by creosotebush at the lower end (Grover and Musick 1990). The relative importance of climate vs. grazing and fire suppression in these so-called "invasions" remains undetermined.

The majority of New Mexico middens that postdate 4000 yr B.P. have been collected from just two sites, the Sevilleta National Wildlife Refuge northeast of Socorro (Betancourt et al. in progress) and Chaco Canyon (Betancourt and Van Devender 1981; Betancourt et al. 1983). Both studies were aimed at detecting shifts in the lower limits of piñon-juniper woodland, which occur at ca. 1920 m on limestone at the Sevilleta LTER and 2000 m on sandstone at Chaco Canyon. Piñon normally extends further downslope on sandstone than limestone, so the higher lower limits on sandstone at Chaco Canyon seem conspicuous.

At the Sevilleta Refuge, piñon occurred ca. 100 m below its present lower limit from ca. 3000 to 40 years ago. Preliminary results at the Sevilleta LTER suggest that a series of severe droughts, culminating in the drought of the 1950's, eliminated piñons from the lowest 100 m of their elevational range on limestone (see section of the 1950's drought). At Chaco Canyon, piñon occurred down to the lowest possible elevations (1860 m) throughout the Holocene, but was restricted above 2000 m sometime between 500-1200 years ago. Betancourt and Van Devender (1981) attributed the reduction in trees to fuelwood harvesting by the Anasazi who built the spectacular ruins at Chaco Canyon. Samuels and Betancourt (1982) showed by computer simulation that the Anasazi could have easily wiped out marginal woodlands in 200 years or less. Similar claims have been made for Anasazi impact in southwestern Colorado (Martin and Byers 1965; Wyckoff 1977; Kohler 1988). In none of these cases, including Chaco Canyon, can climate be ruled out as a contributing factor. Figure 4 shows a conspicuous trough between 750-1250 yr B.P. in the histogram of midden ^{14}C ages. This gap, roughly the same time as the Medieval Warm Period, coincides with the height of Anasazi activity at the time of woodland depletion. This period coincides with an abrupt change to a drier climate and channel trenching in the southern Great Plains (Hall 1990). The tree-ring record for northern New Mexico shows a period of severe droughts in the 11th through 13th centuries (Rose et al. 1981). These droughts appear to have equalled the 1950's drought, which caused broadscale tree mortality in the Southwest.

Man and Piñon

Obviously, Chaco Canyon was not an isolated case where prehistoric overcutting resulted in woodland depletion. Even though it may be politically incorrect to say so, New Mexico woodlands of a thousand years ago were part of a deeply humanized landscape, far from the pristine label commonly assigned to pre-columbian panoramas. As Diamond (1992:319) points out, this revisionist view could be rationalized as "one more piece of racist pseudo-science by which white settlers seek to justify dispossessing indigenous peoples." When reason prevails, however, we realize how difficult and complex it is to practice sustainability. Unlike the Anasazi, we have access to volume-yield tables, computers, and a toolbox full of gadgets that allow us to measure everything from trace gas fluxes to nutrient cycling. Yet, whether or not we can practice ecosystem management and sustainability is still open to question. And like the Anasazi, the Hopi, the Navajo, the Zunis and the Tewa, we too have a conservation ethic. To ignore the role of prehistoric people is to ignore the history of piñon-juniper woodlands, and the possibility that current "invasions" represent recovery from impact only two to three tree generations ago.

The role of prehistoric people as dispersal agents, and possibly in the migrational history of piñon species, has been sorely neglected. Holocene migration of *Pinus monophylla* across mountain islands in the Great Basin might have been delayed, at least in part, until initial expansion of Archaic peoples who used it as a staple (Mehringer 1986). Likewise, human dispersal could explain unusual patterns in geographic variability of *P. edulis* monoterpenes. Sabinene is common in populations from southeastern Arizona-southwestern New Mexico, as well as at Owl Canyon, Colorado (Zavarin et al. 1989). Only traces of this monoterpene occur in populations across the intervening area. Though the possibility of parallel evolution remains, another explanation could involve a prehistoric trade system adapted to the spatial and temporal patchiness of bumper crops (see Steward 1938 for the Great Basin). This system would distribute a local bumper crop to areas that did not experience a mast year. Thus, seed from a bumper crop in the upper Gila could make it to the northern Rio Grande pueblos, where it might be traded to Cheyenne and Arapaho living along the Front Range. The process could have yielded the accidental planting of upper Gila piñon seeds at Owl Canyon (Betancourt et al. 1991). Is this improbable scenario testable? Given recent advances in plant population genetics, it should be.

Ironically, although mast years could be viewed as times of plenty, historically there has been an enigmatic connection between bumper crops and human calamity. The Zuni associated bumper crops with death in the family (Steve Albert, personal communication, 1993), whereas, according to Phillips (1909), the worst ravages of smallpox among New Mexicans occurred during mast years. One explanation is that bumper crops stimulate explosions in local rodent populations, principally packrats (*Neotoma* spp.), and in associated parasites and pathogens, including smallpox and plague (see Ryckman et al. 1981 for an annotated bibliography). Rodent-to-human disease could have been promoted by the harvesting of piñon nuts from caches in active packrat dens (Elmore 1946; Vestal 1952), a practice that may still continue today. Do bumper crops and episodes of plague, or other rodent-related pathogens, coincide both spatially and temporally during the 20th century? In spring

and early summer 1993, a mysterious illness involving flu symptoms and adult respiratory-distress syndrome, fatal in more than a dozen cases, occurred in the Four Corners area (*Time* Magazine, June 14, 1993:57). Speculation about the potential causes of the illness has ranged from plague to anthrax, many of which are associated with rodents and specially packrats. At the time this paper was written, it was found that several patients had developed antibodies to *Hantavirus*, a common Asian virus carried by rodents. Not surprisingly, Navajo medicine men have already made the link between back-to-back piñon bumper crops (in falls of 1991 and 1992), an explosion in rodent populations, and this year's mysterious illness (*Arizona Daily Star*, June 7, 1993). Our guess is that, like their neighbors the Zuni, the Navajo medicine men probably had made this connection before.

POTENTIAL ROLE OF CLIMATE IN MASTING BEHAVIOR OF PIÑON

Because piñons are nonsprouters, reproductive success is largely a measure of the abundance of seed crops and the effectiveness of seed dissemination. Generally, piñons reach conebearing age rather late, often after the tree is 25 years old and one-meter tall; maximum seed production does not occur until the tree is 75-100 years old (Gottfried 1987). The reproductive effort in piñon involves the unique phenomenom of masting, or the production of large cone crops followed by several years of low cone production (2-3 years in *P. monophylla*; 5-6 years in *P. edulis*). Most surprising of all is the synchrony of seed crops across large geographic areas. The influence of climatic variability on flowering, fruiting, and seed germination over what amounts to a three-year reproductive cycle remains unexplored. Equally neglected is the effect of mast years on long-term fluctuations in stand structure.

The evolution of masting behavior in piñons has received little attention. Infrequency of seed years may be controlled by the need to accumulate carbohydrates over a period of a few years to offset allocation of food resources needed to support the costs of flowering and fruiting. This is suggested by suppressed tree growth during flowering and fruiting years, irrespective of favorable soil moisture conditions (Fritts 1976; Floyd 1987). In the tree-ring record, however, a mast year may be indistinguishable from a bark beetle (*Ips confusus*) or herbivorous moth (*Dioryctria albovitlella*) infestation.

Predation by cone beetles (*Conopthorus edulis*) and cone moths (*Ecosma bobana*) (Forcella 1978, 1980) probably enhanced selection for synchrony of mast years. Infrequent and irregular bumper crops inhibit predictability of the food source and minimizes the overall impact of seed predators. In mast years, many millions of seeds mature simultaneously within a limited area, maximizing the chances for germination of seeds produced by individual trees. Seed predators become satiated, unable to consume the entire seed crop; the surplus is available for storage by corvids, the primary dispersal agents (Vander Wall and Balda 1977; Ligon 1978). Individual trees or local stands that produce seed out-of-phase with the rest of the population are at a selective disadvantage with virtually all seeds consumed by predators.

Climate can influence the reproductive cycle over three years. Studies of different pines suggest that there is hormonal competition between vegetative and generative buds, so that environmental stress inhibiting vegetative growth at the end of the growing season can actually induce initiation of cone primordia (Forcella 1981). Winter buds containing cone primordia start to form in August and are fully developed by October. Growth resumes the following May, with cones becoming visible in June. Pollination occurs in June, with most of the pollen discharged over a few days. Only a fraction of the dimension of ripe cones is attained by August of the second growing season. Resumption of growth occurs in the following May. Cones and seeds reach full size by July and mature in September. Cones open and seeds disperse in early fall, three growing seasons (2 1/2 years) after cone initiation (Little 1938; Tueller and Clark 1975; Gottfried 1987).

Entrainment of cone initiation over large geographic areas probably is triggered by some climatic cue. The climatic trigger must inhibit vegetative growth and induce formation of ovulate cone primordia in late summer, it must recur irregularly once every few years, and it must be synoptic in scale. By definition, then, the trigger must be imbedded in interannual climatic variability over the region, and ultimately, in the global-scale climatologies that affect the Southwest (e.g., the position and latitude of the polar jet stream and/or the Southern Oscillation).

Forcella (1981) compared maximum daily temperature at the time of cone initiation (August-September) with a 10-yr (1969-1978) cone production sequence for *Pinus edulis* from five sites in New Mexico. Annual cone production was estimated by counting the number of young cones, mature cones, and cone abscission scars at the 10 most recent annual nodes of each of five branches from each of five trees at each site. The cone crops were negatively and exponentially correlated with mean temperature for the last week of August and first two weeks of September.

The variance of daily maximum temperature is greater in late August-early September than for any other time during the growing season except early spring. Radical drops in late summer temperatures may be explained by advection of cold air with southward penetration of a trough in the westerlies (i.e., a cold front), though the same effect could also result when a tropical air mass is abnormally cool. In North America, month-to-month persistence of atmospheric flow pattern and weather regimes are related to time of year. Persistence is greatest in winter and summer and undergoes sharp regime breaks during or just after the equinoxes. Spring and fall, when the thermal role of the continents is changing in respect to the oceans, are characterized by the greatest change in the zonal westerlies and the greatest variability in weather parameters such as maximum daily temperatures (Namias, 1986). Synoptic-scale cooling during late summer-early fall can also be associated with frontal systems that result when cut-off lows or low pressure

troughs steer moisture from dissipating tropical cyclones off the west coast of Mexico into the southern half of the Southwest. These frontal systems have a higher probability of occurrence during the late summer of an El Niño episode (e.g., August 1992), and tend to precede a wet fall, winter and spring (Webb and Betancourt 1992). The importance of cold fronts vs. Pacific tropical storms as sources of late summer cooling probably varies with latitude. Cold fronts may be more important in Colorado and northern New Mexico, tropical storms in southern Arizona and southern New Mexico. This may explain asynchroneity in bumper crops between southern and northern populations of *P. edulis*.

Reproductive success may ultimately depend on favorable conditions for seedling establishment during the fourth growing season after cone initiation. In west-central New Mexico, heavy seed crops were produced in 1921 (Fogg 1966), 1922-1935 (exact years undetermined), and in 1936, 1943, 1948, 1954, 1959, 1965, 1969, and 1974 (Ligon 1978). The most recent bumper crop occurred in 1991. Surprisingly, some of these years were among the driest in the 20th century.

Presently, there is no reliable regional history of mast years by which to evaluate the role of climate in masting behavior. The merit of making such information available lies not just in the economic value of piñon nuts, or in the health issues related to proliferation of rodents stimulated by bumper crops. It also lies in deciphering the effect of mast years on reproductive success and ultimately, on the structure of piñon-juniper woodlands. A greater effort needs to be expended in developing historical information about mast years from historical documents, field studies (Forcella 1981; 1982), and tree-ring evidence (Floyd 1987). Perhaps we should promote rejuvenation of the annual piñon crop surveys published ca. 50 years ago by the USDA Forest Service (Little 1940; Meagher 1948).

Even with the best data, however, correlation of modern climatic variability and masting behavior would not be completely free of ambiguities. After all, the coupling of weather and bumper crops probably evolved in the context of ice age climates, and not modern ones, that have prevailed over the last 2 million years. During the glacial periods, cool late summers, the climatic trigger for masting in *Pinus edulis* populations, probably were the norm and would have initiated cone primordia almost every year. Perhaps it is no coincidence that the dominant piñons during the last ice age, *P. californiarum* var. *fallax* in the Sonoran Desert and *P. remota* in the Chihuahuan Desert, do not exhibit masting behavior (Little 1966, 1968).

Irrespective of masting behavior, reproductive success by way of tree establishment is wholly driven by episodic conditions favorable for seedling survivorship. And the age structure of piñon-juniper woodlands is determined not only by reproductive success, but by mortality that may be equally episodic.

ECOLOGICAL SIGNIFICANCE OF CATASTROPHIC DROUGHT: THE 1950'S DIE-OFF

The period 1950-1956 constitutes one of 4 major droughts in the U.S. during the 20th century (1899-1904 in the southern U.S.; 1930's or Dust Bowl in the Midwest; and 1980's in the Northwest) (Balchin and Pye 1953; Namias 1955; McDonald 1956; Thomas 1962; Norwine 1978; Griffiths and Ainsworth 1981; Karl and Heim 1990). In the Southwest, it was the worst drought of the century, and 1956 was the driest year (Figure 5). The precipitation anomaly can be attributed to a less sinuous and more northerly polar jet stream, a weakened subtropical jet stream, and a decrease in the frequency of El Niño events. Hot, dry summers followed dry winters in 1951, 1953, 1954, and 1956 (see earlier discussion on three-wave" pattern). Regional wildfires occurred from Florida (Cypert 1961) to southern California (Pyne 1982), activating fire management programs in the southern U.S. that persist today. The drought also yielded an unlikely dieoff of mesquite that only recently had invaded the coastal plains of South Texas (Carter 1964; Archer 1990). Although the magnitude was similar to the 1930's drought, the 1950's received much less fanfare because the agricultural impact was buffered by irrigation from groundwater. Even so, dryland farming and ranching in the Southwest suffered losses in the billions of dollars (*New York Times*, December 9, 1956). The 1950's drought inspired advancements in range hydrology

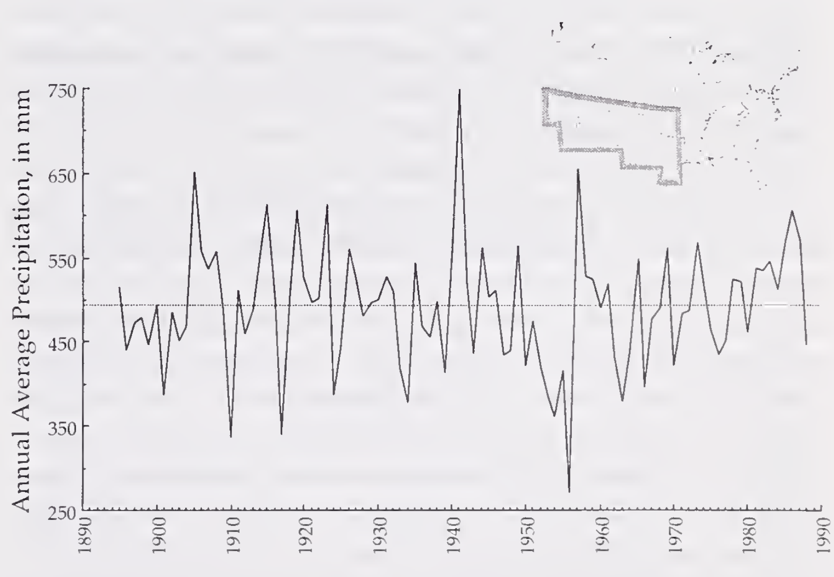

Figure 5. — Areally-weighted annual average precipitation over the Southwest, 1895-1988. Data consist of the monthly climatic averages compiled by the National Climate Data Center of NOAA for each of the 50 climatic divisions in the Southwest (included in the inset area). These monthly averages were summed for each calendar year by climatic division, and then weighted by the ratio of the divisional area to the total land area of the Southwest. The weighted values were then averaged to obtain annual average precipitation over the entire area of the Southwest (see Karl and Knight 1985 for explanation). Note the depth and duration of the 1950's drought.

and water conservation measures, and seemingly justified conversion of piñon-juniper woodland to grassland to improve water yield.

In the Southwest and northern Mexico, massive vegetation dieoffs occurred from the lowland deserts well into the conifer woodlands of the uplands, testimony that the stress tolerance of most species, even drought-adapted ones, was overwhelmed by the 1950's drought. Among the species that suffered broadscale mortality were range grasses (Young 1956; Lohmiller 1963; Herbel et al. 1972; Neilson 1986), saguaro (*Carnegiea gigantea*; Schulman 1956), and a number of conifers, from one-seed juniper (*Juniperus monosperma*) in central New Mexico to Chihuahua pine (*Pinus leiophylla*) in southern Arizona and northern Mexico (Marshall 1957). In some areas, these dieoffs contributed to shifts in ecotonal boundaries along moisture (elevational) and edaphic gradients. Riparian conifers also suffered extensive mortality wherever intermittent streams went completely dry; the woody debris will influence sediment transport and storage, as well as stream biology, well into 21st century. In addition, the 1950's drought probably played a major role in accelerating shrub invasion of grasslands (Lohmiller 1963; Herbel et al. 1972; Grover and Musick 1990).

Although piñon mortality during the 1950's drought is mentioned in the literature (e.g., Potter 1957:128), it remains largely unstudied. Yet the abundant deadwood now conspicuous in piñon-juniper woodlands south of 36°N resulted mostly from the 1950's dieoffs. Mortality during other severe droughts is evident to a lesser degree, for example 1898-1904 (Plummer 1904:18; Lieberg et al. 1904; Phillips 1909). The standing and fallen boles have persisted almost intact because fires have been suppressed in this century. Furthermore, decomposition rates are slow due to the high content of lignin and extractives in conifers and general aridity, which may limit wood rot fungi; termite activity year around may be suppressed by cold winters. Catastrophic dieoffs during the 1950's reset demographic clocks and surely impacted the cycling rates and spatial distributions of carbon and nutrients across the region. In central New Mexico, for example, old piñons (400 years) are unusually rare, whereas they are common on the Colorado Plateau. This discrepancy could have arisen if the last one or two generations of trees experienced catastrophic droughts in central New Mexico, but not on the Colorado Plateau.

Cross-sections of the boles are generally adequate to determine the dates of establishment, death, and other events that caused diminished ring width. The technique of directly aging woody debris to reconstruct stand history is seldom used, even though its utility has long been established (Henry and Swan 1974; Mast 1991). The study of growth patterns evident in ring-width series within the entire population also provides essential information about the importance of microhabitat for surviving drought as well as for considering age-dependent and even frequency-dependent tolerance of drought. More importantly, preservation of the effects of the 1950's drought across the landscape offers the opportunity to directy study ecosystem response over a forty-year period. Community studies of impacted landscapes could yield importantinformationabout successional processes- i.e., patterns of recruitment and changes in vegetation composition and distribution, and disequilibria in carbon and nutrient cycling.

The well-preserved record of the 1950's drought is complemented by an extensive network of tree-ring sites, with many chronologies exceeding 500 years. The severity of the 1950's drought can be evaluated in a long-term context seldom possible. The ring-width chronologies also allow reconstruction of previous dieoff episodes that appear as times of sparse tree establishment and low survival. For example, as a crude approximation of maximum tree and stand age, Swetnam and Brown (1992) reviewed pith dates from ca. 2800 trees (*Pseudotsuga menziesii, Pinus flexilis, Pinus ponderosa, Abies concolor*, and *Pinus edulis*) at 164 tree-ring sites in Arizona and New Mexico. The majority of these trees came from the "driest" microhabitats, or those sites most sensitive to drought and to climatic variability. These are also sites most susceptible to tree death from extreme droughts. The histogram of the oldest 50 piñons in the tree-ring data base shows a sharp increase in the frequency of the oldest established in the early 1600's (fig. 6). Do these data suggest a maximum lifespan for piñons of ca. 350-400 years, or simply the time elapsed since the last "killing" drought? The existence of piñons that exceed 700 years in the Southwest argues for a much longer lifespan. Instead, the pattern in fig. 6A may have resulted from an episode of low survival and recruitment during a catastrophic drought in the 1580's, followed by vigorous regeneration with wet conditions in the

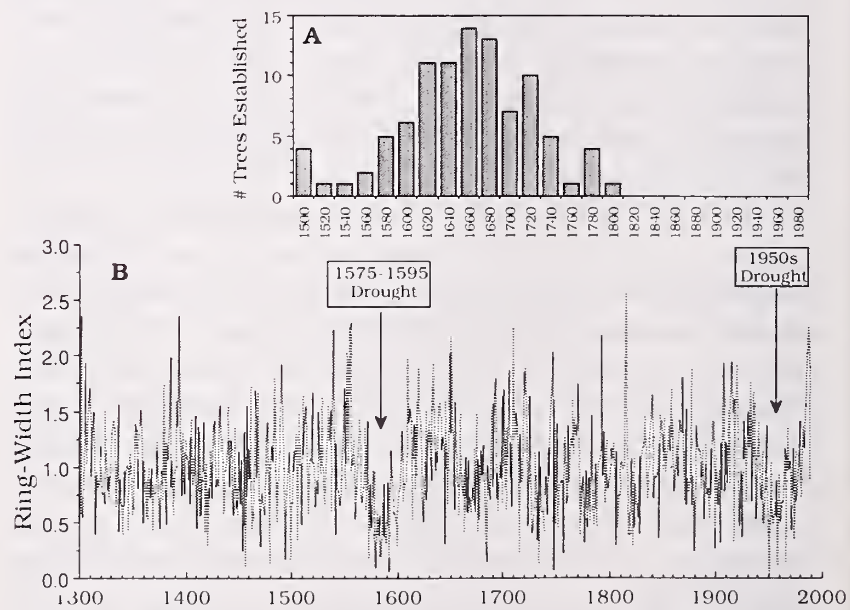

Figure 6. — Tree-ring chronology from Douglas fir near Candelaria Ice Cave at El Malpais National Monument, south of Grants, New Mexico, and histogram of establishment dates for the 50 oldest living piñons in New Mexico used for dendroclimatic reconstructions and archived at the Laboratory of Tree-Ring Research, University of Arizona, Tucson (adapted from Swetnam and Brown 1992). Trees 400 years and older are rare in New Mexico, possibly due to broadscale mortality during the extreme drought of 1575-1595.

early 1600's. If so, should we also expect a surge in establishment to follow the 1950's drought, particularly during the wet 1980's and 1990's? Is there evidence for a recent pulse of regeneration in New Mexico piñon-juniper woodlands? The fact that this simple question cannot be answered adequately points up the need for regional demographic studies.

Below, we use tree-ring evidence to study the influence of climate on the demography of an isolated piñon population on the Sevilleta National Wildlife Refuge, central New Mexico. This site was selected as an extreme example where the 1950's drought resulted in near-extinction of a local population. We envision a network of similar sites, across climatic and edaphic gradients, to evaluate the impact of the 1950's drought on piñon-juniper woodlands throughout New Mexico.

Sevilleta LTER Case Study

The Sevilleta Long-Term Ecological Research Site (LTER) is part of a NSF network of 18 LTER sites that span North America. Ecological research at the Sevilleta LTER is coordinated by the University of New Mexico's Biology Department. The site includes the Sevilleta National Wildlife Refuge, a 100,000-ha reserve free from livestock grazing since 1974, when the land was transferred from the Nature Conservancy to the U.S. Fish and Wildlife Service. The refuge, 75 km south of Albuquerque and 15 km north of Socorro, spans mostly piñon-juniper woodland, juniper savannah, desert grassland, and riparian cottonwood forest, or bosque, from the Los Pinos Mountains (2195 m) west across the Rio Grande (1420 m) to the Ladron Mountains (2797 m). The icon of the Sevilleta Refuge is a small herd of antelope in a grassland recently invaded by creosotebush and dotted with the still-standing snags of one-seed junipers killed by the 1950's drought. Also emblematic of the Sevilleta are piñon-juniper woodlands with interspaces saturated with dead woody debris, another vestige of the 1950's drought.

The impact on piñons is probably most dramatic in an isolated, low-elevation (1585-1705 m) stand at the southeastern corner of the refuge, ca. 150-200 m below its lower limits at sites 5-10 km distant. In this isolated stand, only a hundred out of a few thousand trees survived the drought. The stand occurs primarily on the north slopes and washes that drain into Arroyo Milagro, east of Mesa del Yeso (Socorro, NM, Sierra de la Cruz 7.5° Quadrangle, 34°13°N, 106°42°30°W). The fact that piñons grow alongside one-seed juniper, creosotebush, and ocotillo attests to the site's aridity. The Arroyo Milagro stands of ocotillo represent the fragmented, northern edge of its range in New Mexico.

One-seed junipers at the site also suffered extensive mortality during the 1950's drought. Unfortunately, crossdating of tree rings in this species is problematical, primarily due to the preponderance of both absent and multiple "false" rings; true ring boundaries are often diffuse and hard to distinguish. At lower elevations, the tree grows from several stems at the base, and each of the stems compete for the same resources. It is difficult to crossdate between stems in the same tree, much less from tree-to-tree.

Methods for Sevilleta LTER Demographic Study

Increment cores and cross-sections were taken from 269 trees (about 10% of the total population) to determine recruitment ages for live and dead trees, and approximate years of death. Ages were obtained by crossdating, or matching the patterns of the sequence of wide and narrow rings from tree to tree. Establishment or death could not always be determined to the exact year. Cross-sections and cores were commonly taken within 30 cm of the base of the tree, and the pith was present in many cases. Our pith dates are probably within 10 years of the true establishment age. Outermost rings are within a 1-2 years of death, particularly for trees that died in the 20th century. In decomposing boles, an indeterminate amount of xylem has been eroded, so that the outermost ring may not necessarily represent the year when growth was terminated. Another impediment to dating the year of death is if the last formed ring was "absent"; this is the norm if we accept that severe drought is the most common cause of death. At Arroyo Milagro, many of the trees killed in the 1940's and 1950's retain some bark, have bark beetle galleries on the surface, or the outside ring extends around the entire circumference of the specimen. All of these features suggest that the outermost ring is the terminal one or at worst within a couple of years of it.

Tree-ring widths were measured to reconstruct growth patterns and long-term climatic variability at the site. The latter endeavor was facilitated by availability of cross-sections from 200 dead trees and cores from 31 survivors. By contrast, sampling at a tree-ring site normally consists of paired cores from only 10-25 trees, which would have been inadequate at Arroyo Milagro where missing and false rings are common (Fritts 1976). To correct for declining means and variances associated with increasing tree age, width measurements were standardized by fitting a cubic spline to each series. The ring width for each year was divided by the curve estimate to obtain a ring-width index. The transformed indices for each year were averaged for all trees to develop a site chronology (Fritts 1976). Standardization and averaging selects for the effects of climatic variability shared by trees at the site, and against other variable growth and site factors. The ring-width chronology from Arroyo Milagro was compared to monthly and annual precipitation at Socorro, only 25 km to the southeast and at 1400 m elevation. Mean annual precipitation at Socorro is ca. 240 mm.

Results of Sevilleta LTER Demographic Study

Figures 7 and 8 present age structure data from sampled portions of the Arroyo Milagro population. The data include the upper 0.5 km^2 of the north tributary of Arroyo Milagro, which

was sampled intensively and included less than 10 survivors, and a spot sample of both dead and live riparian trees along the upper 1.5 km reach of the same drainage. We did not sample below the confluence of the north tributary and Arroyo Milagro where there is the greatest concentration of young, live trees. Percentages of trees established in 20-yr age classes were calculated separately for trees that survived and those that died during the 1950's drought (fig. 7). We also calculated the age structure of all trees, live or dead, and the percentages of all deaths by 20-yr interval (fig. 8). Most of the survivors occur along dry washes, but even the majority of "riparian" trees died during this period. The trees sampled along the washes exhibit double rings and erratic series possibly due to the effect of long-term water storage and summer runoff. About 40% of the survivors were established between 1820 and 1860 (90-130 years old in 1950). By comparison, 40% of the trees killed by the 1950's drought were recruited between 1780 and 1840 (110-170 years old in 1950). Regeneration was sluggish after

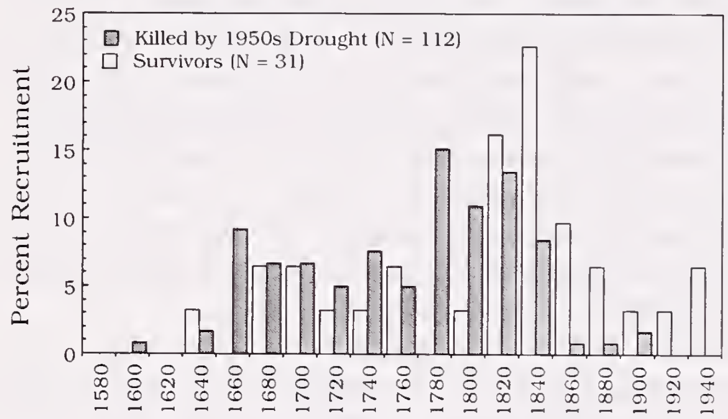

Figure 7. — Percent recruitment by 20-yr age classes of piñons that survived or were killed by the 1950's drought at Arroyo Milagro, Sevilleta LTER, central New Mexico. Percentages were calculated separately for survivors and dead trees.

1860. Although the latter half of the 19th century was relatively dry in central New Mexico, the period 1905-1921 was abnormally wet and would have been favorable for seedling establishment. We can only speculate about the impact of livestock grazing on seedlings at this marginal site. The decrease in recruitment after 1860 also could be due in part to sampling error. We did not core <10 cm in diameter to avoid damage to live trees (smaller trees decompose faster after death). Also, we did not sample below the confluence of the northern tributary (below 1645 m), where young, live trees are concentrated, probably due to damming of ground water by bedrock that outcrops along the stream.

More than 90% of the trees extant in 1940 died before 1956. Figure 9 shows mortality, estimated by the frequency of outermost rings, since 1890. Two-thirds of the outermost dates in this century happened in the 12-yr period of 1943-1954, with the peak year being 1950. Assuming that most of the outermost rings are 1-2 years younger than the actual termination date, the peak dieoff probably occurred in 1951-1955. In general, the near-extinction of Arroyo Milagro population can be attributed to sluggish recruitment since 1860 and catastrophic dieoffs during 1950's drought. Had recruitment remained constant in the late 19th and early 20th century, a large part of the population would have consisted of trees less than 100 years old. These younger trees might have been less susceptible to the drought (see Carter 1964 for survivorship of young mesquite).

Though drought clearly precipitated the piñon dieoff at Arroyo Milagro, the proximate cause of death is unknown. Drought predisposes tree populations to insect oubreaks. For example, an outbreak of piñon beetles (*Ips confusus*) coincided with extensive piñon mortality at Bandelier National Monument in the 1950's (Chansler 1964). Beetle galleries, which are omnipresent in dead piñons, reflect breeding in both weakened and dead trees. During the 1950's drought, however, the *coup de grace* may have been weather itself. Trees were subjected to unusual heat loads in 1951, when a broad suite of species, from one-seed juniper to ponderosa pine, died in New Mexico. High

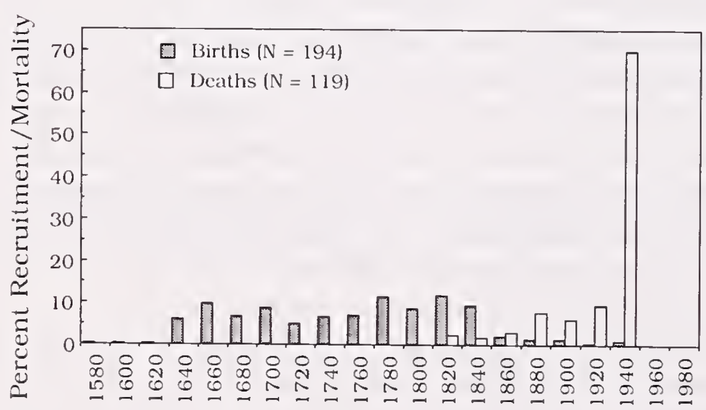

Figure 8. — Percent recruitment and death by 20-yr age intervals for all piñons sampled at Arroyo Milagro, Sevilleta LTER, central New Mexico.

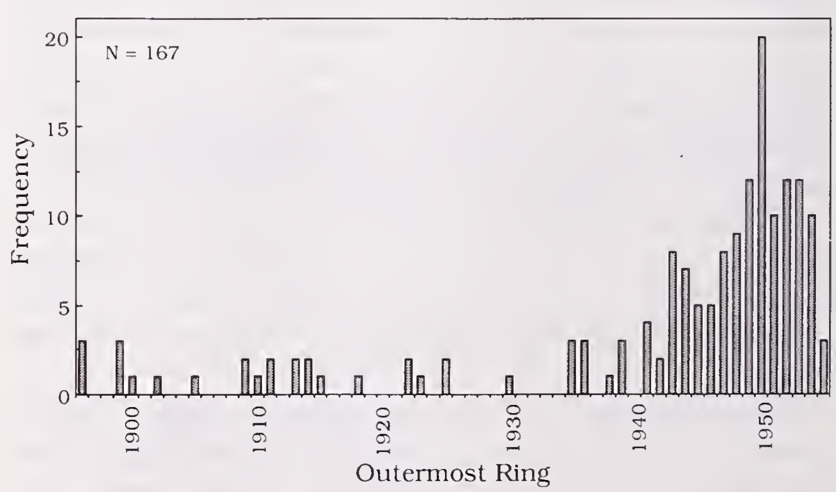

Figure 9. Twentieth-century mortality by year of outermost ring in downed trees sampled at Arroyo Milagro, Sevilleta LTER, central New Mexico.

heat loads, in the absence of adequate soil moisture, can cause dieback through prolonged air embolism or cavitation of the xylem, whereby tracheids and/or vessels become filled with air impeding xylem transport (Sperry and Tyre 1988).

On the Jornada del Muerto, 100 km south of Arroyo Milagro, the maximum temperature equalled or exceeded 38°C on 45 days, as compared to an average of 8-10 days a year (Herbel et al. 1972). In summers following severe winter-spring drought, a reduction in evaporation (soil moisture) increases the sensible heat flux, which in practice means warmer surface temperatures locally. In other words, the incident solar radiation that is normally spent towards evaporating soil moisture heats up the ground instead. The situation is exacerbated if the monsoons fail in July, the month of greatest incident solar radiation. Reduced soil moisture during late winter and spring could help induce and amplify a warm, dry summer in interior continental areas, both due to local effects and modification of large-scale atmospheric circulation (Namias 1988). Such an effect has been proposed for the perpetuation of droughts such as the Dust Bowl, the 1950's and the summer of 1988. Empirical, statitiscal evidence for this phenomenon (Namias 1988) is now confirmed by simulations of soil moisture effects on summertime climate using general circulation models (Oglesby and Erikson 1989).

A ring-width chronology was developed from the Arroyo Milagro cross-sections and cores for the period 1598-1991 (fig. 10). The 20th century part of the chronology closely mirrors both interannual and decadal variations in August-to-August precipitation at Socorro (fig. 11). Note that the driest years of record (e.g., 1904 and 1925) were not prolonged enough to cause extensive mortality within the stand (fig. 9). Also, there was minimal recruitment during a relatively wet period from 1905 to 1921 (fig. 7 and 8). Both the ring-width and precipitation series show that 1942-1956 was extremely dry, that the drought ended with a return to wet conditions during the 1957-1958 El Niño episode, and that dry conditions resumed during 1962-1968. The 1950's drought was preceded by a period of dry summers in the 1940's (see also Neilson 1986). In the longer ring-width chronology (fig. 10), prolonged (10 yr) droughts also occurred during 1667-1681 and 1730-1750. It is easy to imagine how these events, as well as the earlier drought of 1575-1595 (fig. 6), might also have reset demographic clocks through broadscale tree mortality in New Mexico piñon-juniper woodlands. The association of these severe droughts and fire history in piñon-juniper woodlands is not well documented. In ponderosa and mixed-conifer forests, though, 1748 stands out as the worst fire year in a 300-yr record of fire scars and fire statistics for Arizona and New Mexico (Swetnam and Betancourt 1990). It was also one of the driest years in the Arroyo Milagro tree-ring chronology, and culminated in the severe drought of 1730-1750 (fig. 10).

The 1667-1681 drought, for example, may explain our inability, until recently, to bridge the gap between tree-ring chronologies from architectural timber at Gran Quivira, a 13th-17th century pueblo 60 km due east of Arroyo Milagro, and living piñons on Chupadera Mesa. There can be little doubt

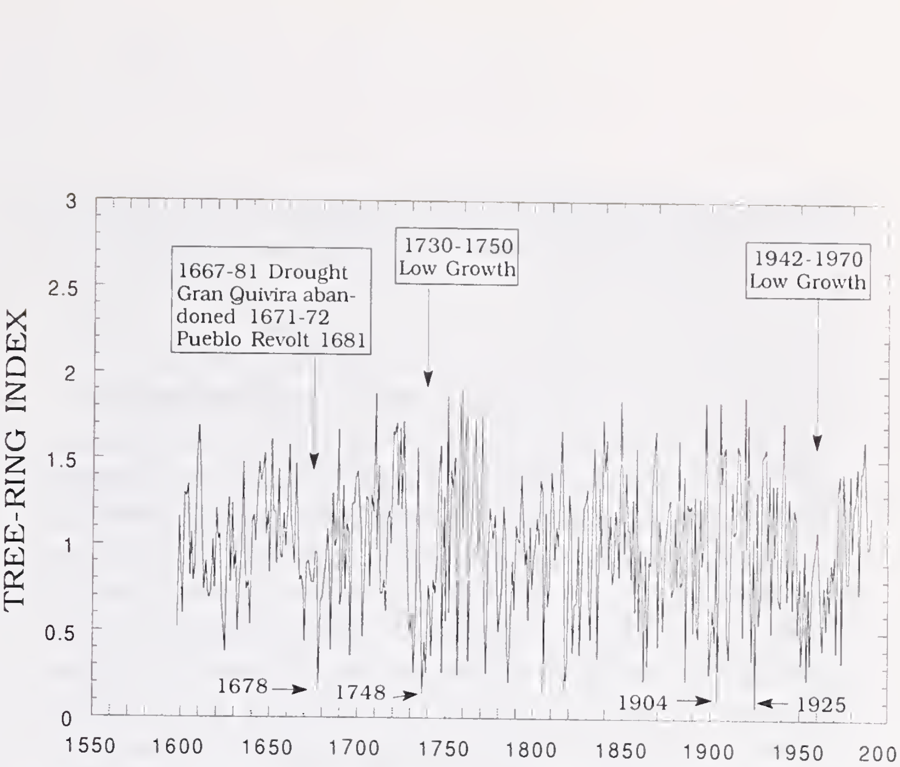

Figure 10. — Ring-width chronology from piñons sampled at Arroyo Milagro, Sevilleta LTER, central New Mexico, 1598-1991.

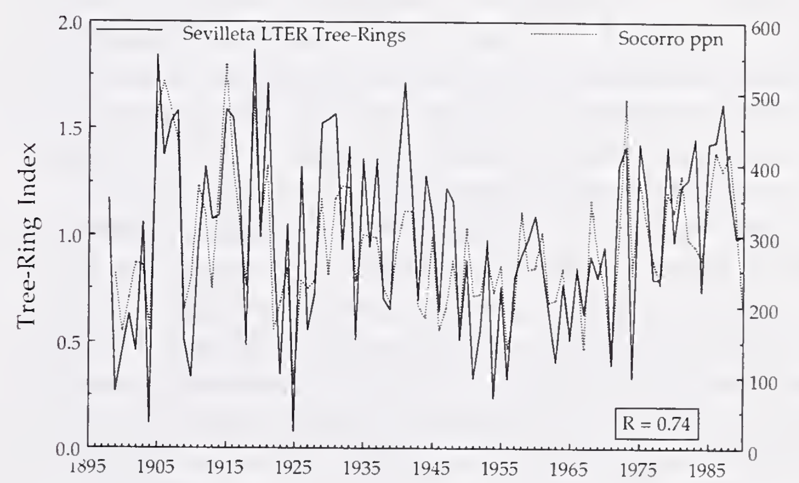

Figure 11. — Comparison of tree-ring chronology from Arroyo Milagro, Sevilleta LTER, central New Mexico and August-August precipitation series from Socorro, 25 km to the southwest, 1896-1988. Note that the tree-ring series captures both the high-frequency (annual) and low-frequency variability (decadal) in the precipitation series.

that the drought of 1667-1681 figured heavily the abandonment of Gran Quivira in 1671-1672. By 1669 no crops had been harvested for 3 years, and more than 450 people, or roughly half of the inhabitants, had starved to death, "lying dead long the roads, in the ravines, and in their huts" (Hackett 1937:271-272; Vivian 1975). Epidemics, Spanish oppression, and Apache "outbreaks" in 1670 and 1672 dealt the final blow to the weakened inhabitants of Gran Quivira, and the group fled to villages and missions in the Socorro area and El Paso. Consider that the system of Spanish taxation and forced labor, known as *encomienda*, became entrenched during the wet period of 1642-1663, and that these demands did not ease up during the ensuing drought. Perhaps it was no coincidence that the Pueblo Revolt of 1680 followed quickly on the heels of the worst year of the drought (1678: fig. 11). If the 1950's are any indication, the 1667-1681 drought may have caused extensive piñon mortality on steep, south-facing slopes, the kinds of sites preferred for development of ring-width chronologies. This may partly explain the scarcity of trees that date to the early half of the 17th century in the Gran Quivira area. By contrast, living

trees that became established in the late 1600's and early 1700's are common in central New Mexico, but must have survived the 1730-1750 drought.

Ecological Significance of the 1950's Drought

Biological and ecological processes involved in ecosystem adjustment to climatic variation have been studied primarily at the organismic and community level, rarely at the ecosystem or regional scale. Yet, a hierarchical approach is now crucial to clarify how vegetation figures in global geochemical and hydrological cycles, and to predict ecological change with future climates. Because it is difficult to reconcile local, intrinsic processes with external influences on the whole ecosystem, what is needed is a tracer, a regional perturbation that cascades from one scale to the other. We propose that the 1950's drought provides such a tracer for piñon-juniper woodlands in New Mexico. At hand is a model system for studying the direct impacts of catastrophic drought across geographic scales, as well as 40 years of ecological adjustments. An understanding of this impact should make it possible to predict future susceptibility of woodlands to broadscale dieoffs.

Disturbance as the principal driver of long-term population dynamics poses a difficult challenge for successional models. In the only attempt to model succession in piñon-juniper woodlands, Samuels and Betancourt (1982) assumed a "climax" community of constant density; temporally-constant environmental conditions; a "typical" age at death of 400 years for piñons and 500 years for junipers; and annual decay rates of 10% for dead woody debris. To estimate the "typical" age structure in piñon-juniper woodlands using this equilibrium model, different initial conditions were simulated for 1000 years. A stable age distribution, or convergence of standing crop, was approached by 400 to 500 years, regardless of the original age structure. Whether or not stabilization of these patterns can occur depends on the frequency of local as well as regional disturbances. Episodic mortality due to catastrophic drought challenges the notion that piñon populations ever achieve equilibrium, that is, having relatively constant and equal mortality and recruitment rates. The tree-ring record shows a high probability that a "killing" drought will occur during the potential lifespan of a piñon pine, say 350-500 years. It should follow then that piñons seldom reach their potential maximum longevity, or that they only rarely die from senescence. More often than not, their lifespan is truncated by disturbance, be it severe drought, fire, or insect and pathogen outbreaks.

Mortality is one of the least understood processes in ecology, even though information on tree death is critical for calculating sustainable yields and protecting ecosystems. Tree death serves many ecological functions- e.g., shifting of ecotonal boundaries; modification of population and community structure; shift from biomass to necromass; release of light and nutrients; as a habitat for wildlife and decomposers (Franklin et al. 1987). The woody debris produced by catastrophic dieoffs can store significant amounts of carbon over the long term, a role that has virtually been overlooked in carbon budgets of forest and woodland ecosystems (Harmon and Hua 1987).

Disequilibrial conditions due to drought recurrence are not necessarily restricted to semi-arid ecosystems. Broadscale mortality due to severe droughts has been recorded from North Carolina (1700 mm mean annual precipitation) (Barden 1988) to New Zealand fog forests (1500-3000 mm) (Jane and Green 1983). Disequilibrial conditions in carbon storage are apt to have the longest influence in semi-arid ecosystems, where decomposition of woody debris is measured at centennial, not decadal, scales. At Arroyo Milagro, boles of trees that died more than 100 years ago persist on the surface. How much of the woody debris from the 1950's drought will be retained 100 years from now, and what was long-term impact on population dynamics and carbon and nutrient cycling? These questions need to be addressed if we seriously intend to take an "ecosystem" approach to managing piñon-juniper woodlands.

Although the 1950's drought produced the most widespread tree mortality of the century, more recent dieoffs offer research opportunities elsewhere in the West. For example, Great Basin shrubs suffered extensive mortality following an excessively wet period in 1983-1985 (McArthur et al., 1990). And during a 7-yr drought in past decade, tree mortality has been widespread across the northwestern U.S. (Wickman 1992). This may be an opportune time to study dieoffs if we consider that the probability of extreme weather events, be they floods or droughts, may be altered by future "greenhouse" climates.

SUMMARY

Among ecologists, there is growing appreciation for the influence of history and climatic variability on community dynamics. Still, historical factors have yet to receive the empirical and theoretical attention given to other "equilibrial" processes such as competition and predation. Even among self-professed "disturbance ecologists," there remains hope that a self-reproducing climax state exists as an average condition on a relatively large spatial scale (Sousa 1984). Even this seems unlikely given the regional consequences of the 1950's drought, and the many times this occurred in the last millennium, or in the few tens of tree generations since the end of the last ice age. Obviously, this makes New Mexico piñon-juniper woodlands that much harder to understand and that much more difficult to manage.

Although community instability at all scales may thwart strategies for sustainability using steady-state models, there is little reason for despair. The influence of history and climate on New Mexico piñon-juniper woodlands can be untangled using some of the tools and approaches discussed in this report. The ability to crossdate tree rings means that we can relate the cadence of regional births and deaths to something as remote as the sea surface pressure differences between Darwin and Tahiti, or the expansion and contraction of the circumpolar

vortex. Ring-width chronologies allow us the luxury of relating population dynamics to climate, also at at interannual resolution. Knowing the ecological impact of the 1950's drought, for example, we can simulate how similar droughts in the distant past might have affected population structure. Obviously, there are opportunities and needs for real-time successional models that take history and variability into account. The piñon-juniper ecosystem is now being managed in the absence of ecological modeling that considers nonequilibrial and episodic population dynamics.

Finally, the large number of references cited in this report can be deceptive. There has been no systematic use of the fossil record, be they tree rings or packrat middens, to clarify the role of climate and land use in population dynamics. By summarizing the relevant literature and offering new examples, we hope to demonstrate the utility of blending approaches from paleoecology, biogeography, and ecology to yield a comprehensive history of piñon-juniper woodlands in the western U.S.

ACKNOWLEDGMENTS

Much of the work reported in this paper evolved from our work at the Sevilleta National Wildlife Refuge, in collaboration with the University of New Mexico's Long-Term Ecological Research (LTER) Program. In particular, we thank Ted Stans, U.S. Fish and Wildlife Service, and Jim Gosz and Bob Parmenter, University of New Mexico, for unfailing support. We acknowledge assistance in the field by Carlos Mendoza, Ray Turner, Steve Tharnstrom, Gary Bolton, and Bob and Cheryl Parmenter. We also thank Dave Pratt for providing the data in Figure 5 and Tom Swetnam for far-ranging discussions and the data in Figure 6. Finally, the senior author owes a special debt of gratitude to Tom Van Devender for helping jump-start his research on New Mexico piñon-juniper woodlands in summer 1979.

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Piñon-Juniper Ecosystems Through Time: Information and Insights From the Past

Thomas R. Cartledge and Judith G. Propper[1]

Abstract — In understanding present-day ecosystems and deciding how they should be managed, it is important to understand how they came to be as they are today. Both natural and human forces have brought about changes in past ecosystems that may not be readily apparent in today's landscapes. Data gathered from archaeological sites, including faunal, floral, and climatological data, can be used to reconstruct important aspects of past ecosystems and to determine how they changed through time. Human beings have been an integral part of piñon-juniper ecosystems in the Southwest for over 10,000 years. Archaeological evidence of past human use is abundant and has the potential to yield information crucial to our understanding of these ecosystems today. Current evidence indicates that piñon-juniper woodlands were not pristine and unmodified prior to the arrival of Europeans in the Southwest, but had a complex history of natural and human-caused variability and change.

INTRODUCTION

The USDA Forest Service is responsible for management of some 190,000,000 acres of National Forests and National Grasslands, containing a wide range of natural and heritage resources spread across 38 states and Puerto Rico. For most of its 102-year existence, the Forest Service has had a commodity-oriented management emphasis focused primarily on product out-puts. Recent years have witnessed a growing insistence from both inside and outside the organization that the agency must broaden its emphasis and adopt a new management philosophy which recognizes that National Forest System lands provide a variety of resources in addition to commodities, as well as essential habitat for a host of plant and animal communities which are intricately interrelated within ecological systems. Just how to implement ecosystems management on vast tracts of forested lands and the specific architecture of such a management strategy are topics of much current discussion.

It is within this context that the management of piñon-juniper ecosystems is being explored and addressed in the Southwestern Region. In this paper we will attempt to show how the study of the past can contribute valuable information to our understanding of ecosystems in general, and of piñon-juniper ecosystems in particular. We will do this by: 1) offering some thoughts on the importance of understanding how ecosystems have changed through time, including the role human beings may have played in these changes; 2) exploring some of the data sets and analytical techniques that archaeologists use to study past ecosystems, including two examples of paleoenvironmental reconstructions; 3) summarizing a few of the many archaeological studies that have dealt with the question of human interactions with past ecosystems; and 4) addressing past human interactions with piñon-juniper ecosystems and the implications of these data for current day piñon-juniper ecosystems management.

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ECOSYSTEMS MANAGEMENT AND THE PAST

Some would contend that the Forest Service has been doing ecosystems management for years, but that we simply have not identified our management as such. Others, including the authors, would hold that while the Forest Service has been managing various specific resources based upon ecological principles, we have yet to achieve a fully integrated ecosystems management strategy. The distinction made by ecologist E.P. Odum (1971) between autecology and synecology is relevant here:

Autecology deals with the study of the individual organism or an individual species. Life histories and behavior as a means of adaptation to the environment are usually emphasized. Synecology deals with the study of groups of organisms that are associated together as a unit. . . . In the former instance attention is sharply focused on a particular organism with the purpose of seeing how it fits into the general ecological picture, much as one might focus attention on a particular object in a painting. In the latter instance, the picture as a whole is considered, much as one might study the composition of the painting (Odum 1971:6).

From this perspective, the Forest Service has made considerable progress toward management based upon autecological principles but now needs to make the shift to a synecological perspective of resource management; to look at the whole picture, at broadly defined ecosystems, and to understand their overall composition and the interrelationships among subsystems.

The Human Dimension

A recent Forest Service task group, convened to explore the question of general ecosystems management, concluded that, "Ecosystems have three interrelated dimensions: the physical (landforms, minerals, geology, etc.), the biological (plants and animals), and the human dimension (social, economic, spiritual, cultural, historic, etc.)". While the task group recognized the importance of an historic perspective with specific reference to the human dimension of ecosystems, overall, there has been little attention given to the fact that ecosystems themselves have histories of which human beings are a part, and that a knowledge of ecosystem history is extremely important to current day management.

An Archaeological Perspective

We suggest that ecosystems management will fall short of its objectives if the strategy does not include a historic/prehistoric perspective. If we intend to effectively "manage" these highly complex systems, we must gain a thorough understanding of how the ecosystems under our management came to be as we see them today. An understanding of ecosystems history, or paleoecology, is both necessary and essential to sound ecosystems management.

If we go back far enough in time (4-5 million years), early hominid populations are just one of the groups of "animal" communities living and surviving through direct and total interaction with the natural environment. Through time, we see these hominid populations slowly changing and diverging from other anthropoid populations, most notably in their social behavior. There is an ever-growing sophistication of technology, giving humans an ever-increasing dominance over other creatures with whom they competed for various resources. Thus, through time, human groups become further and further enmeshed in social, cultural, and technological environments. While some societies become increasingly further removed from direct interaction with their natural surroundings, no human society has ever ceased to interact with and affect its natural environment.

Some might assume that the history or prehistory of ecosystems is simply beyond our grasp, but this is not the case. The fact that human beings have been an integral part of ecosystems through time presents us with a very effective avenue for learning about past conditions and interrelationships. Archaeological sites hold a wealth of information about the natural environment. Employing commonly-used archaeological methods and techniques of data recovery and a variety of interdisciplinary analyses, archaeologists can, with various degrees of precision, reconstruct the character of past ecosystems and address the nature and magnitude of changes, natural and human-caused, that have occurred through time.

ARCHAEOLOGICAL EVIDENCE FOR PAST ECOSYSTEMS

Archaeologists carry out studies of human history and prehistory through analyses of the material remains found in archaeological sites. Many of these remains are, at the same time, indicative of the surrounding environment in which a community lived. In the course of interacting with their surroundings, humans procure and transport to their living and camp sites various resources which can tell us a great deal about those surroundings. Archaeological sites thus provide a microcosmic concentration of data and information reflective of various components of the surrounding environment.

Methods and Techniques

Archaeological researchers utilize various methods and techniques to carry out paleo- environmental studies. Some were developed strictly within the discipline of archaeology and some have been borrowed from other disciplines, but all attain their greatest efficiency when applied archaeologically due to the chronological precision that archaeology provides. For purposes of this discussion archaeological paleoenvironmental studies can be divided into three general categories: faunal studies, floral studies and climatological studies.

Faunal Studies

One question that has always been a focus of archaeological inquiry involves the nature of the subsistence base of prehistoric human populations. What kinds of foods did past peoples

consume and what proportion of their diet was provided by each? All past human populations depended to various degrees upon hunting of animals to provide one portion of their overall subsistence. Quite commonly conditions are such that the bones of hunted animals are preserved in the deposits that make up various kinds of archaeological sites. Recovered bones are analyzed to determine what kinds of animals are represented and in what proportions in order to determine past subsistence behavior. In addition, human habitation sites attract various creatures which are not necessarily consumed as food but whose bones become incorporated into archaeological deposits.

There is also indirect evidence of prehistoric fauna. When an animal is killed with a stone projectile point or butchered with a stone knife or a hide is prepared with a stone scraping tool, a blood residue remains on the tool. Borrowing from molecular biology and biochemistry, archaeologists are now applying analytical techniques that allow identification of blood antigen residue on stone tools as old as 10,000 years (Hyland et al. 1990). Depending upon various preservation factors and the particular analytical technique used, individual species within a single genus or family can be identified.

Floral Studies

Past human populations also depended to various degrees upon gathered wild plants for another portion of their overall subsistence. Most gathered plant material was brought back to a camp or habitation site for preparation and consumption, and such material is sometimes preserved in archaeological deposits. At open sites if seeds, nuts or various plant parts were charred by fire, they are often preserved and can be recovered archaeologically through a technique known as floatation. In dry cave situations virtually all plant material may survive regardless of whether or not it is fire-charred. Dry caves also frequently preserve human coprolites which contain seeds and various bits of plant materials that were consumed as food. Apart from plants used as food, plant materials were also transported to archaeological sites for use as building material and fire wood and are often preserved in the archaeological record.

Two other techniques that allow archaeologists to determine what kinds of plants were present at sites, even in the absence of visible plant parts, are pollen analysis and phytolith analysis. Plants brought to a camp or habitation site often have pollen grains adhering to them; these grains drop to the surface as plants are processed and become incorporated into site deposits. Indirect evidence of plant materials is provided by plant phytoliths. Opal phytoliths are silica bodies with characteristic shapes produced during plant growth by partial or complete silification of plant cells, cell walls, and intercellular spaces; the silica derives from water containing dissolved silica that is taken on by the plant during growth (Bozarth 1990). Many types of phytoliths are preserved in the soil for long periods of time. Microscopic analysis discloses shapes and sizes specific to particular plant taxa.

Climatic Studies

Archaeologists have long been interested in human behavioral responses to past environmental change and fluctuation. Such studies have focused heavily upon paleoclimate and have sought to determine past patterns of variation and change in the amount and distribution of precipitation. Paleoclimatological studies borrow freely from geomorphology and hydrology but gain considerable chronological precision when combined with dated archaeological sites and materials. Tree-ring studies perform a dual function in paleoclimatological research. Variations in year-to-year patterns of ring growth provide data on amounts and distribution of precipitation, while overall patterns in ring sequences, when compared to master charts, allow precise dating of any given specimen. Using tree-ring specimens recovered from archaeological sites, master charts going back hundreds of years have been developed for various localities over large regions. From this, dendrochronologists have determined widespread and localized patterns in paleoclimatic variation and change through time.

The kinds and quantities of pollen grains found in natural soils are indicative of vegetation that grew in a given area at the time the soils formed. The kinds and distributional patterns of vegetation developed through pollen studies are reflective of past climate. Pollen grains are incorporated into and preserved in various depositional contexts. Geomorphologists and botanists rely upon pollen studies to reconstruct past climatic patterns, but their studies often suffer from a lack of dating precision. When pollen samples are gathered from deposits at archaeological sites, chronological precision is greatly enhanced through association with relatively well-dated materials, and climatic reconstruction can be achieved in much greater detail.

Hydrological studies have also proven very useful in paleoclimatic reconstruction. Various alluvial deposits indicate periods of soil aggradation and periods of soil degradation, tied to higher and lower water table levels which, in turn, indicate temporal changes in the pattern and distribution of precipitation. In some deposits in the Southwest, trees have been buried in the deposits themselves; these trees can be directly dated by their growth rings, thus dating the depositional episode. Sometimes archaeological materials, such as fire hearths, are incorporated into alluvial deposits as well and provide a basis for relatively tight dating. Sites constructed on top of alluvial deposits can likewise provide a basis for chronological control.

From the above discussion it can be seen that data and information recovered from archaeological sites make it possible to determine what plants and animals were being consumed at a particular point in time, as well as the nature of vegetative communities around a given site and indications of past climatic variation and change. These data are, at the same time, evidence of the ecosystem in which the inhabitants of a given site participated.

Paleoenvironmental Reconstruction

We would now like to briefly summarize two different projects in which archaeologists, working with other scientists, have made extensive use of paleoenvironmental reconstruction. One is focused upon a relatively small area, the vicinity of Chaco Canyon in New Mexico; the other is very broad and looks at paleoenvironment over the entire Colorado Plateau region. Our purpose in presenting these examples at this point in the discussion is to illustrate what can be learned from paleoenvironmental studies; some of the findings with regard to human behavioral responses are discussed in a subsequent section.

Chaco Canyon

Our first example pertains to a somewhat localized situation. During the late 1960s the National Park Service established a cooperative program with the University of New Mexico to undertake a long-term reevaluation of the Chaco Anasazi. This program involved the expertise of numerous scientists in archaeology, geography, geology, botany, biology and other special areas. One of the objectives of the project was reconstruction of the past environment in the Chaco area. In a volume entitled "Environment and Subsistence of Chaco Canyon", Gillespie (1985) summarizes research aimed at paleoenvironmental reconstruction for the entire Holocene Period from about 12,000 years ago to present.

Gillespie drew upon data from floral studies, pollen studies, geological studies, and faunal studies to document important changes in climate and biotic communities over the past 12,000 years at Chaco and in the surrounding San Juan Basin. A relatively cold, moderately wet climate prior to 8,000 B.P. supported mixed conifer forests along canyons with cold desert steppe vegetation on mesa tops. Following 8,000 B.P. piñon and juniper began to migrate into the area to replace mixed conifer forests, while warm desert grasslands replaced sagebrush-dominated cold desert steppe. The cause of these vegetative changes is thought to have been the arrival under generally warmer conditions of a monsoonal circulation system with warm wet summers. From around 5,000 B.P. to about 2,000 B.P. evidence of increased aridity is found in the context of generally cooling temperatures. Essentially modern conditions have persisted since about 2,000 B.P., but with a period of above average summer rainfall and temperature from A.D. 950-1130 and a period of prolonged summer drought from A.D. 1130-1180.

The Colorado Plateau

Our second example focuses on the results of a very extensive paleoenvironmental study conducted in conjunction with an archaeological project on the Colorado Plateaus aimed at explaining certain aspects of Anasazi sociocultural stability and change (see Dean et al. 1985). The study was conducted by a group of scientists, including four archaeologists, a geologist, and a botanist who were interested in human behavioral change and stability as a partial function of environmental stability and change. The success of such an investigation was, of course, predicated upon an ability to characterize paleoenvironment as accurately as possible and to isolate and identify periods of fluctuation, stability and change through time.

Combining data from archaeology, geology, palynology and dendrochronology, the researchers identified both low- and high-frequency environmental processes thought to have occurred widely over the Colorado Plateaus from A.D. 1 to the present. Figure 1 illustrates these environmental fluctuations. With regard to low-frequency processes the research revealed ". . . episodes of valley floor deposition separated by periods of channel entrenchment and of soil formation on stabilized floodplain terrace surfaces. Aggradation and degradation are correlated with and caused by, respectively, increases and decreases in groundwater and effective flood levels in the valley bottoms" (Dean et al. 1985:540).

Episodes of rising groundwater and floodplain aggradation on the one hand and falling groundwater and erosion on the other were found to occur on a cyclic basis (see Figure 1A). The pattern of this low-frequency process was derived based on chronostratigraphic studies of alluvial sediments. Instead of correlating different stratigraphic units based on standard geomorphological techniques of sediment composition similarity or terrace morphology, the study used independent dates (archaeological material, radiocarbon and tree-ring) to date units and correlate different stratigraphic sections. Figure 1A depicts a cycle of about 500 to 550 years for these episodes. For example one repetition of the cycle is shown between about A.D. 1300 and A.D. 1850. It is interesting to note that we are currently experiencing one of these cyclic episodes of falling water tables and erosion that began in the late 1800s. This suggests that natural forces may be just as important as cultural factors (over grazing, fire suppression) in bringing about the changes noted in erosion and vegetation patterns in the Southwest over the last century.

Low-frequency processes of high and low effective moisture were investigated separately using pollen data from archaeological and alluvial contexts, again employing archaeological, radiocarbon and tree-ring dating techniques for independent chronological control. The correlation between the pollen generated curve and the hydrological curve is evident in Figure 1B.

High-frequency environmental variability for the period in question was determined using independent analyses of tree-ring data from mostly archaeological contexts. Figure 1C displays dendrochronological data expressed as decade-long departures of tree growth from the mean of the entire southwestern chronology. Temporal patterning is shown by the frequency structure of the departure sequence. Periods of rapid occillation correlate generally with periods of low effective moisture and soil degradation.

These two examples of past climatic reconstruction reveal a highly complex picture of a changing environment and raise some interesting questions with regard to ecosystem management and restoration.

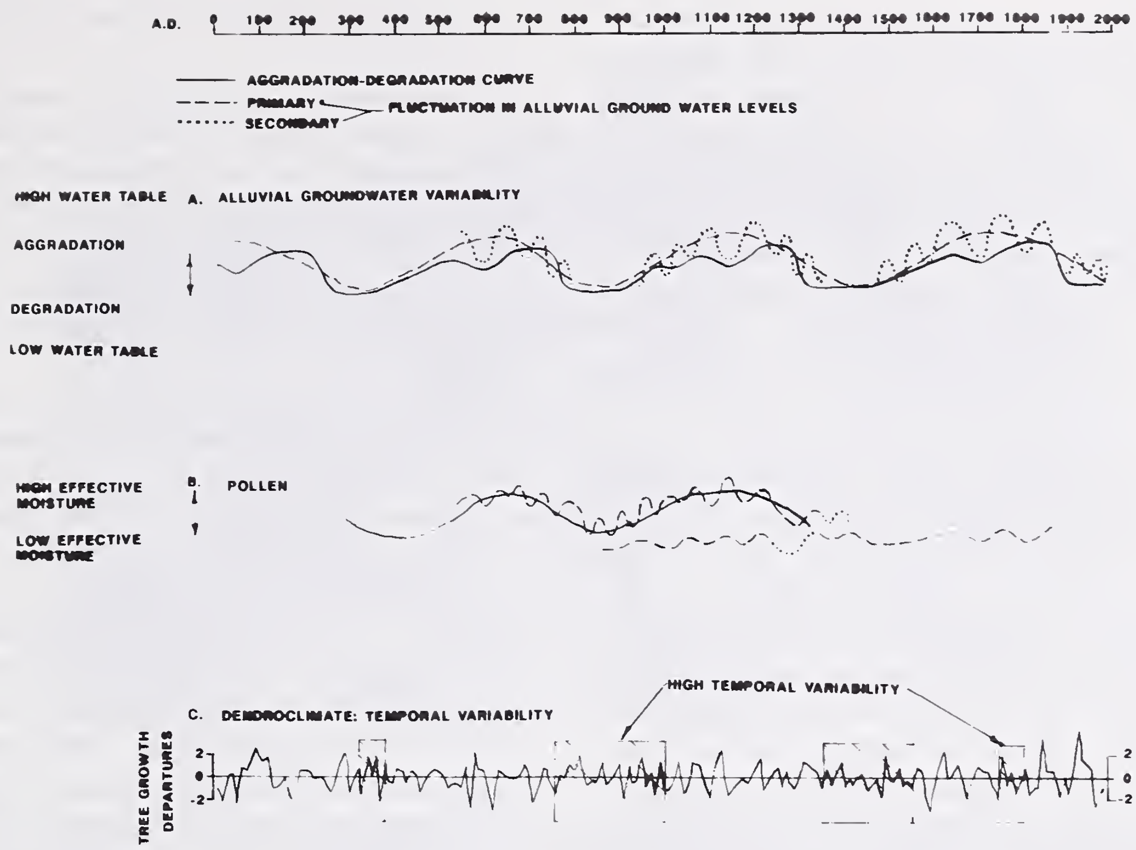

Figure 1. — Environmental Variability on the Southern Colorado Plateaus, A.D. 1-1970. (After Dean et al. 1985).

HUMAN INTERACTION WITH PAST ECOSYSTEMS

The relationship between people and the environment has been a topic of archaeological inquiry in the Southwest for over 100 years. During that time, explanatory models have evolved from simple cause-and-effect constructs, for example the Great Drought theory for large-scale Anasazi abandonment in the late13th century, to more complex models involving a large number of interrelated environmental and cultural variables. Our perception of the nature of the human-environment relationship has also evolved from a view of human cultures existing more or less in balance with the environment until jolted by a major environmental change to a realization that the relationship between people and their environment is probably always in a state of flux:

> *More and more scholars have begun to recognize that the normal state for many cultural systems is dynamic disequilibrium, that there is seldom a delicately balanced relationship between resources and population - resource imbalance is a fact of life...(Gumerman 1988:15).*

The picture that emerges is one of interaction between a constantly changing environment and a constantly changing human system, with the human system changing not only in response to the environment but to many other factors as well, e.g., population, social and economic variables, ideology. In spite of this complexity, human interaction with the environment is still considered highly significant in shaping the course of human history and prehistory in the Southwest.

Behavioral Response to Environmental Variability

A look at Dean, et al.'s (1985) reconstruction of paleoenvironmental data over the past 2,000 years (fig. 1) reveals a great deal of environmental variability, even at this very broad level. How did human populations respond to these changes?

Types of Responses

High frequency environmental processes, such as short-term drought, fluctuations in seasonal rainfall, and temperature fluctuations can have significant effects on wild resource availability, growing seasons, and crop production. Human populations can respond to these high-frequency changes with a variety of buffering techniques (Jorde 1977; Schlanger 1988). Hunting and gathering groups and mobile horticulturalists might respond by increasing the frequency or extent of seasonal movements. Increased mobility would be less feasible for populations in later times more dependent on domesticated crops and permanent settlements. In these cases, behavioral responses might include increased food storage, diversification of field locations, intensification of farming techniques, development or expansion of exchange systems, increased reliance on wild food sources, increased ceremonialism and intervillage cooperation, population aggregation or dispersal, a shift of settlement location between uplands and lowlands, or in severe cases, abandonment and relocation to another area.

Low-frequency fluctuations would normally be less apparent, and behavioral responses more gradual. In some cases, however, when population is relatively high, when subsistence strategies are stretched to the limit, or when the onset of low-frequency change is sudden or is amplified by high-frequency processes, effects on human populations could be abrupt. Such conditions could make certain areas uninhabitable regardless of buffering techniques and could contribute to fundamental cultural change.

Examples

Archaeological research on the Colorado Plateau over the past 25 years suggests that correlations do exist between paleoenvironmental fluctuations and culture change. One well-documented example involves a relatively brief deterioration of hydrologic conditions which coincided with a major dendroclimatically documented drought in the last half of the 12th century. Effects of this high frequency episode of drought, falling water tables, and arroyo cutting were compounded by relatively high population levels in several parts of the Plateau. These environmental fluctuations, small blips in Figure 1, undoubtably played a role in the population shifts and organizational changes of this period.

One such change occurred on Black Mesa in northeastern Arizona where the A.D. 1150 drought follows a period of population growth and coincides with the abandonment of the northeastern portion of the mesa (Gumerman and Euler 1976; Karlstrom et al. 1976). The abandonment appears to have been intentional and perceived as permanent, since almost all of the artifacts were removed, including manos and metates. It appears that at least some of the population moved to the interior of the mesa and located near seeps and springs. Similar shifts in settlement location are noted in nearby Long House Valley (Dean et al. 1978).

In the Dolores area of southwestern Colorado, population seems to have responded to high-frequency environmental fluctuations in the period prior to A.D. 1100 by moving between higher and lower elevations to take advantage of rainfall. After A.D. 1100, however, population concentrated and increased in the lower, dryer reaches of the region in spite of poor long term conditions and periods of moderate drought. Schlanger (1988) suggests that this represents a behavioral response that involved a shift in field locations from mesa tops to canyons and stream valleys where watering by hand or by water collection and diversion features would have made continued agriculture possible.

A final example involves the onset of long-term deteriorating conditions in the late 1200's which was accompanied by a persistent and severe short-term drought. Although it is no longer believed that the Great Drought single-handedly caused the abandonment of Mesa Verde and much of the San Juan basin, it is accepted that adverse environmental conditions probably played a significant role in that process. In this case, probably due to a number of interrelated factors, buffering mechanisms were not able to sustain the population.

Human Impacts on Past Environments

Of equal interest in our efforts to understand the relationship between human systems and the environment in the Southwest is the study of how past cultures affected the ecosystems of which they were a part. The use of fire by American Indians in historic times is well-documented. Other obvious impacts include the effects of hunting, clearing of land for agricultural fields, and harvesting trees for fuelwood and construction materials.

In Chaco Canyon, for example, it is estimated that as many as 200,000 trees were used in the construction of just the ten major ruins. By around A.D. 1030 there was a shift in construction material for beams from ponderosa pine to spruce and fir. Betancourt, Dean, and Hull (1986) suggest this indicates depletion of suitable-size ponderosa pine in the uplands bordering the canyon. Spruce and fir beams would have had to be transported from Mt. Taylor near Grants, New Mexico, or from the La Plata and San Juan Mountains in Colorado, both at least 75 kilometers away. The amount of effort and organization this would have required is staggering. There are, for example, around 6,000 spruce and fir beams in the ruin of Chetro Ketl alone.

DATA FROM PIÑON-JUNIPER WOODLANDS

Piñon-juniper ecosystems were used extensively by prehistoric populations in the Southwest for more than 10,000 years. Piñon-juniper woodlands contain the greatest diversity of native plant and animal resources used as food by prehistoric human groups in the Southwest. According to Gumerman (1984), thirty-four plant species commonly occur throughout piñon-juniper woodlands on Black Mesa; twelve of these are food resources; eleven are collected as raw materials; and four are used medicinally. Food species include banana yucca, piñon pine, Gambel oak, Indian rice grass, Mormon tea, prickly pear, and one-seed juniper. The woodlands also overlap with the elevations most favorable for rainfall agriculture and thus were favored locations for prehistoric farming communities.

Archaeological Evidence

The importance of piñon nuts in prehistoric diets is well-documented, especially for Basketmaker populations. A number of researchers have noted a strong association between Basketmaker sites and current piñon-juniper woodlands (Matson and Lipe 1979; Wills and Windes 1989). Wills and Windes (1989) suggest that local piñon nut masts may have provided the impetus for fall population aggregation at the large Basketmaker III pithouse village of Shabik'eschee in Chaco Canyon, dating from A.D. 500 to 750. At Turkey Pen, a Basketmaker II site (A.D. 200-400) on Cedar Mesa in

Figure 2. — Example of a pueblo ruin, one of many types of archaeological sites found in piñon-juniper woodlands on National Forests in the Southwestern Region.

southeastern Utah, analysis of coprolites indicates that piñon nuts were second only to corn in terms of abundance in the diet (Aasen 1884; Matson and Chisholm 1991). Studies at Mesa Verde (Stiger 1979) also document the importance of piñon nuts in Basketmaker III through Pueblo II times after which their frequency appears to drop off.

Today the piñon-juniper woodlands contain abundant evidence of past human use and, in fact, contain the highest density of prehistoric sites on many National Forests in New Mexico and Arizona (fig. 2). Lithic scatters, which may date back thousands of years, occur in many settings throughout the woodlands. Recent studies have shown that, far from being redundant, amorphous deposits of artifacts and debris, these sites may contain discrete, highly-structured clusters representing the remains of short-term campsites established over many thousands of years (Sullivan 1972; Phillips 1993). Many lithic sites contain features such as fire hearths or storage pits just below the ground's surface. Even in the absence of such buried features, recent advances in techniques to date stone tools, to identify raw material sources, and to determine how tools were manufactured and used, increase the research potential of these sites for filling in the gaps in our knowledge about that long block of time before the development of permanent villages. That block of time makes up 95% of the record of human existence in the Southwest.

The piñon-juniper woodlands also contain abundant remains of pithouse villages that preserve the record of the transition to agriculture and permanent settlements. Here again, surface indications may be limited to small sherd and lithic scatters, with or without surface depressions. Excavation, however, can reveal remains of structures, storage pits and outdoor activity areas. Remains from later puebloan periods include cliff dwellings and pueblo ruins of from one to over a thousand rooms, often with extensive networks of associated field houses, field systems, rock art, and other features.

Past Human Impacts on Piñon-Juniper Ecosystems

Even a brief look at these sites leaves little doubt that their inhabitants must have had a significant effect on the surrounding landscapes and biotic communities. A number of recent archaeological studies provide clues to these impacts.

One line of evidence comes from Mesa Verde. Here, based on analyses of coprolite, flotation, pollen, and faunal samples, Stiger (1979) presents evidence for extensive mesa top deforestation prior to abandonment. Through time, piñon nuts in the diet decreased as corn and beans increased. Bighorn sheep and cottontail declined as deer and jackrabbits increased, as would be expected in cultivated and open shrubby environments. Pollen analyses indicated that during the early Basketmaker occupation, percentages of pine and juniper pollen were similar to today. The pollen record during pueblo times, however, is dominated by grasses and other disturbance species. These human effects on the ecosystem would have coincided with the onset of adverse natural environmental changes, adding another dimension to the question of abandonment.

In the Dolores River Valley in Southwestern Colorado, Kohler and Matthews (1988) reached a similar conclusion regarding reduction of piñon-juniper woodlands based on a study of the remains of prehistoric fuelwood. They analyzed charred wood

fragments from 107 well-dated fire hearth and fire pit contexts at the Grass Mesa site, occupied from A.D. 700 to 900. Results indicate that use of piñon and juniper, abundant in early features, declined through time as shrubby species increased. Kohler and Matthews go on to suggest that reduction of nearby woodlands and related effects on the ecosystem may have played a key role, along with environmental change and other factors, in the relatively short-lived occupation of many early Anasazi sites.

A similar process on a much larger scale has been suggested for Chaco Canyon, where macrobotanical remains from packrat middens suggest the presence of a more extensive, though marginal, piñon-juniper woodland in the canyon prior to the period of intensive Anasazi occupation (Betancourt and Van Devender 1981). Samuels and Betancourt (1982) use a simulation model to demonstrate that the Anasazi population would have destroyed the woodland, irrespective of environmental change, through fuelwood harvest.

IMPLICATIONS FOR MANAGING PIÑON-JUNIPER ECOSYSTEMS

This review of information derived directly or indirectly from archaeological research in the Southwest has relevance for contemporary efforts to understand and manage piñon-juniper woodlands. Implications can be summarized as follows:

1. Piñon-juniper woodlands did not exist in an ecologically stable condition prior to the arrival of Europeans as is sometimes assumed. The woodlands no doubt underwent thousands of years of change in productivity, composition, and extent due to low-frequency and high-frequency environmental fluctuations characterized by changes in water-tables, hydrologic aggradation and degradation, arroyo cutting, effective moisture, seasonal variations in rainfall patterns, and temperature fluctuations.
2. Piñon-juniper woodlands did not exist in a pristine, unaltered condition prior to the arrival of Europeans. Human beings have made extensive, and in some cases intensive, use of piñon-juniper woodland resources for thousands of years.
3. In order to understand piñon-juniper ecosystems today, it is crucial to understand what those ecosystems were like in the past and what forces, including human beings, affected them. Metaphorically, what we see today is but the last frame in a ecological film strip hundreds of miles long. In our efforts to manage and manipulate piñon-juniper woodlands today, or to define their desired future conditions, it is essential that we view these woodlands in their historic and prehistoric contexts.
4. Prehistoric sites, so abundant in piñon-juniper woodlands, hold keys to understanding the natural and human forces that contributed to both change and stability in piñon-juniper ecosystems in the past. These sites are fragile and non-renewable and contain irreplaceable scientific information, as well as educational, social, and traditional cultural values. These values should be taken into account in planning for the future management of piñon-juniper ecosystems. Treatments such as chaining, pushing, grubbing, and in some cases prescribed fire and fuelwood harvest can damage or destroy these sites. Inventory, evaluation, and appropriate protection or mitigation of significant archaeological resources should continue to be an integral part of piñon-juniper ecosystems management.
5. Far more research is needed on the effects of long-term and short-term paleoenvironmental variation on piñon-juniper ecosystems and on the impacts of past and present human use on these ecosystems. Any future piñon-juniper research initiatives should include a program of research designed to address these important questions.

In conclusion, because of the abundance, diversity, and excellent preservation of archaeological resources in the piñon-juniper woodlands of the Southwest, we have a unique opportunity to add incredible time depth to our understanding of these ecosystems. Such understanding will enhance our ability to manage piñon-juniper ecosystems wisely and responsibly in the future.

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Ecology and Diversity of Piñon-Juniper Woodland in New Mexico

William A. Dick-Peddie[1]

Until recently there has been little research conducted upon woodland vegetation. This has been largely because woodland vegetation was of less economic importance than either forest or grassland vegetation.

OCCURRENCE OF PIÑON-JUNIPER VEGETATION

One of the most important factors dictating where a given type of vegetation is found is "available moisture". Available moisture is a complicated factor. It is a function of precipitation (amount, form, season, frequency, and intensity); infiltration rate (surface material and slope); percolation (soil structure and texture); and rate of evapo-transpiration from plants and soil. Vegetation types have different available moisture requirements. It is not surprising then that in New Mexico, forest, woodland, grassland, and scrubland are established on a gradient of decreasing available moisture. Woodland has a higher available moisture requirement than grassland but lower than that required by forest.

CHARACTERISTICS AND DIVERSITY OF PIÑON-JUNIPER WOODLAND AND JUNIPER SAVANNA

Woodlands are characterized by tree species whose canopies do not overlap and whose sizes are smaller than top-canopy forest tree species. Tree density in woodlands varies from 280 trees/acre down to 130 trees/acre. Scattered stands with densities of less than 130 trees/acre are considered to be savanna stands.

This symposium is concerned with one type of woodland - Piñon-Juniper Woodland. Even though there are no piñon pines in New Mexico savannas, the juniper savannas are considered part of the Piñon-Juniper Ecosystem at this symposium. You must remember that Piñon-Juniper Woodland in New Mexico includes a number of different species in different combinations, in different parts of the state. The composition and structure of the Piñon-Juniper types vary on an available moisture gradient. Moir and Carleton (1987) proposed three subzones of woodlands for New Mexico as follows:

1. Mesic (cool, wet) closed woodlands - Tree cover: 50-80%, Height of tallest trees: 7-13m

2. Typical or model open woodlands - Tree cover: 30-50%, Height of tallest trees: 4-8m

3. The aridic (warm, dry) juniper savannas - Tree cover: 5-30%, Height of tallest trees: 5m

There are two species of piñon pine found in New Mexico. They are the Colorado Piñon (*Pinus edulis*), and Border Piñon (*P. discolor*). There are six or seven species of juniper in the state but the most widespread are Alligator Juniper (*Juniperus deppeana*), One-seed Juniper (*J. monosperma*), Rocky Mountain Juniper (*J. scopulorum*), and Utah Juniper (*J. osteospema*). I have classified the vegetation of Piñon-Juniper Woodland and Juniper Savanna found in New Mexico (Dick-Peddie, 1993). Series as used by the Forest Service was used as the category above the basic category of Association (Community type or Habitat type). The classification recognized the following Series (the number in parentheses is the number of distinct Association-found in the Series):

Coniferous Woodland

Colorado Piñon-One-seed Juniper Series (10)
Colorado Piñon-Alligator Juniper Series (4)
Colorado Piñon-Utah Juniper Series (1)
Colorado Piñon-Rocky Mountain Juniper Series (1)
Colorado Piñon-Mixed Juniper Series (3)
Colorado Piñon-Mixed Juniper Series (1)

Mixed Woodland

Colorado Piñon-Oak-Juniper Series (2)

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Savanna

One-seed Juniper Series (8)
One-seed Juniper-Rocky Mountain Juniper Series (1)
Utah Juniper Series (1)

You can see that the greatest number of Associations (10) are found in the Colorado Piñon-One-seed Juniper Series. This series is the most widespread in the state. It is interesting that Woodin and Lindsey (1954) noted that although One-seed Juniper was the most important juniper in New Mexico woodlands, it is replaced in the north (Colorado) by Rocky Mountain Juniper and in the south (Mexico) by Alligator Juniper. Alligator Juniper is usually found in New Mexico at the upper limits of the P-J Woodland and some even suggest that Alligator Juniper is a subdominant member of the Ponderosa Pine Forest in much of the state. Large old Alligator Junipers are found in the Sacramento Mountains in areas which were cleared of Ponderosa forest in the past.

I have outlined for you the type and degree of diversity found in the Piñon-Juniper Woodland and Juniper Savanna vegetation of New Mexico. It is obvious to all of us that Piñon-Juniper Woodland and Juniper Savanna are generalized, generic terms and that single or uniform management schemes cannot be successfully applied to these diverse ecosystems. Each Series or possibly even each Association should be approached independently as to manipulation and management.

CHANGED AND CHANGING PATTERNS OF PIÑON-JUNIPER AND JUNIPER SAVANNA VEGETATION

Lastly, I want to address changes in the patterns of Piñon-Juniper and Juniper Savanna vegetation during the last 100 years.

Synecologists (community ecologists) have been wrestling with the concept of "competition" for many years. It now appears that in plants competition is at best subtle and may only be operative at the time of germination. Actually, as we instruct our young school children, plants tend to "share" the environment. In fact we should expect selective pressures to stimulate a reduction of competition through the incorporation of adaptations which permit a species to use different features of the environment and/or at different times than other species in the habitat. I have gone in to this so we will understand that the establishment (ecesis) of a species on a new site denotes that there is not only an opening in the community but that the microhabitat meets the needs of the new arrival. Knowledge of this ecology avoids the misleading concept implied by the terms "invasion" and "invader". These terms imply a dynamics of the advance of one species into another species' habitat and outcompeting it, thereby pushing it out. A great deal of money has been spent over the years, based upon this "invader" premise, to remove the "invader" species as the culprit responsible for the decline in vigor and density of the initial species. Rather it should be assumed that the establishment of the "invader" species serves as an indicator or symptom that the initial habitat has been modified and may no longer be optimum for the initial species.

My view is that the rapid increase in the amount of juniper savanna in New Mexico over the past 100 years is an example of ecesis following microhabitat modification. A more striking example can be seen in north-central to northwestern New Mexico where the microhabitat has been so modified that grassland vegetation has disappeared and there now is a transition from Piñon-Juniper Woodland to Great Basin Desert Scrubland. Changing patterns where Colorado Piñon is expanding appears to actually be its re-establishment on previously Piñon-Juniper sites (Sallach, 1986).

I would suggest that brush removal on grassland might well hasten grass recovery provided that post-removal management rectifies the situation which allowed the brush to become established in the first place. If such management is not economically feasible, periodic removal will be necessary.

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Zuni Cultural Relationships to Piñon-Juniper Woodlands

Ronald K. Miller and Steven K. Albert[1]

Abstract — Piñon-juniper woodlands are the most abundant and most culturally important habitat type on the Zuni Indian Reservation. Zunis have used piñon and juniper trees as a source of food, medicine, fuel, and construction material for hundreds of years. Zunis also rely heavily on many piñon-juniper associated plant and animal species. These resources are utilized for economic, social, cultural, and religious purposes. Natural resource personnel working on the Zuni Reservation use multi-disciplinary approaches to sustainable resource development to ensure that the resource is protected and that cultural values are preserved. Solicitation and understanding of tribal values is a necessary component of natural resource planning.

INTRODUCTION

"For us, woodlands are not just terminology—they are our very life! We depend on them for firewood, for cooking, and for keeping warm. Piñon trees, New Mexico's state tree, also provide us with nuts that we consider a delicacy, if not a necessity. Woodlands provide valuable wildlife habitat and protect our soils from eroding. They are part of us." — Councilman Edison Wato, Zuni Pueblo (Testifying in Phoenix, Arizona during hearings on the National Indian Forest Resources Management Act, March 6, 1991.)

Many people in the Southwest recognize the importance of piñon-juniper woodlands. The Zuni Indians of northwest New Mexico especially fit this category. As described in the quote by Councilman Wato, piñon and juniper woodlands are woven into the very fabric of Zuni life. The bonds that connect the Zuni people to the resource exist in all aspects of their life, from historical to social to religious. In fact, the connection is so tightly woven that the culture and the resource are inseparable. Of the 1978 Zuni archaeological sites surveyed before 1987, 64% (1257) were either located in piñon-juniper woodlands or had a strong piñon-juniper component. From the piñon and juniper wood used for heating and cooking, to the annual collecting of piñon nuts, to the harvest of woodland birds and mammals for cultural purposes, the piñon-juniper ecosystem supports and sustains the Zuni community in countless ways.

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Of the 419,026 acres that comprise the Zuni Indian Reservation, 46% of the land, or 194,618 acres, is covered with piñon-juniper woodlands. Woodlands on the Reservation range in elevation from 1877 meters (6100 feet) to 2369 meters (7700 feet).

ZUNI WOODLAND TREE SPECIES

The primary woodland tree species that grow on the Zuni Reservation are piñon pine (*Pinus edulis*) and three types of juniper—Rocky Mountain juniper (*Juniperus scopulorum*), one-seed juniper (*Juniperus monosperma*), and alligator juniper (*Juniperus deppeana*).

The Zuni names for these four species are:

- *He'sho* - Piñon
- *Homa:k'yahaya* - Rocky Mountain Juniper
- *Ayhik'o* - One-seed Juniper
- *Asuk'o* - Alligator Juniper

While the Spanish named the piñon for the nut it produces, the Zunis named the tree after its valuable sap. "He'sho" literally means "pitch". Piñon pitch has been used by Zunis for centuries as an antiseptic (Stevenson 1915), as a pottery glaze, and was even applied to stones used in baking bread for religious occasions (Cushing 1920). Pitch is also burned to purify the air during certain religious ceremonies. Probably the most wide-spread use of the piñon both on and off the Reservation, however, is for the nutritious seed: the piñon nut.

PIÑON NUTS

Archaeological remains show evidence that piñon nuts were eaten in Zuni as long ago as A.D. 1000[2] (Brandt and Ruppe 1990a). Piñon nuts were also discovered preserved in cooking jars in burials at the ancient Zuni village of Hawikuh when that site was excavated by F.W. Hodge between 1917-1923 (Mills 1976).

Frank Hamilton Cushing, the noted archaeologist and ethnologist who lived for many years in Zuni during the latter part of the 19th century, described the use of ground piñon nut as shortening, flavoring, and as a thickening agent in cooked foods (Cushing 1920). Today, an estimated 80% of the Zuni people still collect piñons (K. Manolescu, unpubl. data).

Although many Zuni people collect piñon nuts strictly for personal consumption, others derive a substantial economic benefit from harvesting and selling the nuts. Many who choose not to sell the nuts do so with the belief that piñon nuts are a gift from the Creator and, as such, are not to be sold (Owen Bobelu, pers. commun.).

A bumper crop of piñon nuts occurred in Zuni and other parts of the Southwest in 1992. For weeks, people searched the woodlands for the abundant seeds. Large crops are sometimes viewed as a mixed blessing because of a particular belief many Zunis have about the relationship between themselves and the piñon nuts. It is said that the occurrence of many Zuni deaths precedes an abundant crop of piñon nuts (Lowsayate 1985).

Piñons are not the only woodland tree that provides a food crop. Junipers provide food for Zunis as well. Favorite Zuni dishes such as blood sausage and corn-bread are sometimes flavored with juniper berries. Historically, alligator juniper berries were also eaten, either raw or steamed (H. Johnson, pers. commun.). Stevenson (1915) also reported that a tea of juniper twigs were drunk by pregnant women immediately prior to childbirth in order to promote muscular contractions.

ZUNI USES OF PIÑON AND JUNIPER WOOD

In addition to the nuts and berries provided by woodland trees, inhabitants of the Zuni area have relied on the wood of the piñon and juniper for centuries for heating, cooking, and building purposes. There is evidence that as the local pre-historic population grew, the Zuni River Valley was subject to deforestation (Brandt and Ruppe 1990b).

Current use of piñon and juniper wood on the Zuni Reservation is extensive. In 1992, an estimated 9,200 cords of fuelwood were burned for cooking and heating purposes. The fact that the demand for fuelwood is so great on the Reservation could be a cause for concern if this resource could not sustain itself. At least for the present the supply of fuelwood on the Reservation far exceeds the demand of the residents. This is particularly true because the traditional method of gathering fuelwood has been to collect only dead material. The forestry permit system, as outlined in the Zuni Forest Products Policy, encourages this traditional practice to continue. Tribal members do not need a permit to collect dead wood. However, a permit is required any time live trees are cut.

As the tribal population increases, the luxury of having an abundant wood resource could change. Recently, the Zuni Tribal Council passed a resolution banning the harvesting of alligator

[2] *However, some researchers believe early human use of piñon nuts in Zuni and other sites was not extensive due to piñon nut ecology (Floyd and Kohler 1989). Piñon pines exhibit large reproductive events, followed by many subsequent years of little or no seed. This reproductive strategy may temporarily overwhelm seed-eating predators, and ensure that some seeds survive to produce new trees. This aspect of piñon ecology probably made the piñon nut an unreliable food source. Floyd and Kohler also cite evidence that pre-historic use of piñon nuts as a food source was inversely related to both the degree of agricultural intensification, and use of the piñon tree as fuel wood.*

juniper. This species has the most restricted range of any of the woodland tree species on the Zuni Reservation and has recently come under increasing harvesting pressure. Although the wood is a favorite among wood-cutters, the Tribal Council acted decisively when the future sustainability of this important tree was judged uncertain. The current ban protects all of the remaining alligator juniper, Reservation-wide.

Junipers are still the most desired wood species for use in the outdoor rock and mud ovens. Zuni bread is cooked in the ovens year-round, especially during ceremonial events, by heat generated from juniper wood. Huge piles of juniper can be seen stacked beside the ovens all around the pueblo. Boughs from Rocky Mountain juniper are also used to clean out the ashes and coals after the ovens have reached the right temperature. Before the advent of electricity, Zunis commonly made torches from juniper bark (Cushing 1920).

Piñon wood, on the other hand, is sought after to heat homes. Many of the traditional red rock houses still exist in the Pueblo, and most of these houses are heated solely with wood. Several woodland projects and a tribal wood yard have been established in Zuni in recent years to provide for the local fuelwood need while still protecting the woodland resource (Miller 1993). The woodland projects are set up using uneven-age silvicultural methods designed to retain the healthiest trees and the best piñon nut producers.

Historically, the needles of the piñon tree were consumed as a remedy for the symptoms of syphillis, while the buds and shoots of the tree were eaten by members of the Great Fir Society in order to produce female children (Stevenson 1915).

Other important uses of piñon and juniper wood relate to the ranching trade. Junipers are prized fence-post material because their natural tannins protect the wood from insect attack and most types of decay, even long after the tree is dead. A permit must be obtained before cutting fenceposts, since the junipers are alive when harvested. In 1992, permits for 2,975 fenceposts were issued. Sheep corrals also utilize the junipers. In this case, the boughs of the juniper provide the construction material.

WOODLAND ASSOCIATED WILDLIFE

Just as Zunis are dependent on piñon and juniper wood to maintain their lifestyle, so are they dependent on the wildlife that utilizes the piñon-juniper woodlands. As many as 39 species of mammals, 120 species of birds, and 13 species of reptiles and amphibians are found in piñon-juniper habitat on the Zuni Reservation (Hanson 1980). Many of these same animals play important roles in Zuni tradition and culture.

Mammals

Mule deer (*Odocoileus hemionus*), which depend on Zuni's middle elevation woodlands, are probably the most important wildlife species in Zuni culture. Deer are hunted for traditional or religious purposes as well as for recreation. Significant aspects of the Zuni religion revolve around the relationship of the Zuni people and the deer. Many Zunis believe that deer are the spirits of Zuni ancestors. Therefore elaborate ceremonies surround the harvesting of deer, and proper protocol is to be observed both while field dressing the deer, and later when the animal is brought home (Lahaleon 1985, Panteah 1985).

Mule deer in Zuni spend most of their time on piñon-juniper covered mesa-tops. A recent aerial survey of big game on the Zuni Reservation showed the importance of piñon-juniper woodlands as winter deer habitat. In January 1993, 100% of the deer were located in the piñon-juniper habitat. These areas support high densities of important deer browse such as Gambel oak (*Quercus gambelli*), wavy leaf oak (*Quercus undulata*), antelope bitterbrush (*Purshia tridentata*), and mountain mahogany (*Cercocarpus montanus*). The woodlands also provide necessary thermal and hiding cover for the deer.

Other woodland mammals such as cottontails (*Sylvilagus nutallii*), black-tailed jackrabbits (*Lepus californicus*), gray fox (*Urocyon cinereoargenteus*), bobcats (*Felis rufus*), coyotes (*Canis latrans*), and raccoons (*Procyon lotor*) are used by Zunis for religious or traditional purposes (Stroh 1990). Of special interest are some of the larger predators that use woodlands, such as the black bear (*Ursus americanus*) and mountain lion (*Felis concolor*). These species are considered sacred, and can only be hunted by initiated members of specific religious societies.

Birds

The definition of "game bird" must be somewhat modified by wildlife biologists working in Zuni or other Indian pueblos, where the hunting of woodland songbirds is a common practice. Instead of meat being the desired result of a successful hunt, many Zunis are constantly seeking feathers. Approximately 70 species of birds are hunted by Zunis for cultural purposes (Ferguson and Hart 1985). An estimated 75% of the Zuni population makes use of feathers for traditional dress or the making of prayer sticks. Some birds are also used for medicinal purposes. For example, bluebirds (*Sialia* spp.) are used to provide a remedy for spider bites (Sanchez 1985). Many of the more sought after birds such as the northern flicker (*Colaptes auratus*), jays (*Cyanocitta* spp.) and bluebirds are dependent on piñon-juniper woodlands.

WOODLAND ASSOCIATED PLANT SPECIES

Many woodland-associated plant species are also utilized in Zuni culture. Big sage (*Artemesia tridentata*) is used by the Zuni people as medicine for ailments ranging from colds and sore throats, to earaches, arthritis, and cramps (Tsethlikai 1985). It has also been used as a foot deodorant

Yucca (*Yucca* spp.) provides another example. The fruits are an edible delicacy, while the roots are used for shampoo. Other parts of the yucca plant have been used for items as diverse as headpieces, brushes for painting pottery, prayer sticks, sandal strings, and varnish. Zuni jewelers also use the plant to restore the natural luster to turquoise (Lonkesion 1985). Many other woodland associated plants too numerous for the scope of this paper have both traditional and modern day uses in Zuni culture.

CONCLUSION

A resource containing so many valuable assets, and so interwoven into the tribal culture is something that the Zuni people feel strongly about sustaining. Therefore, studies are being conducted Reservation-wide to increase understanding of woodland ecology. The tribal natural resources staff, under the newly formed Zuni Conservation Project, and Bureau of Indian Affairs resource personnel work closely with the community.

Resource management projects follow a sustainable, inter-disciplinary approach. A recognition of cultural values and solicitation of tribal member input are prerequisites. Staff members work in conjunction with tribal advisory teams composed of local land users or their representatives. For example, the Zuni Fish and Wildlife Department has recently established an advisory team composed of a mix of tribal members who utilize wildlife for religious purposes, and those who use wildlife for recreational purposes. In this way, resource planning will be sensitive to the entire spectrum of tribal values. The Zuni Conservation Project has even hired a cultural anthropologist to interview tribal members to ensure that cultural values are integrated into resource planning. Community input is solicited **before** projects take place so that sustainable management practices can be implemented that are not only sensitive to cultural needs, but actually spring from them. In Zuni, the culture and the woodland resource are so inexorably linked that the fate of one may very well determine the fate of the other.

ACKNOWLEDGMENTS

We wish to thank the Bureau of Indian Affairs Zuni Agency, and the Zuni Conservation Project for support during the writing of this paper. We also thank New Mexico Office of Cultural Affairs, Historic Preservation Division for supplying archaeological data. Carol Brandt, Zuni Archaeology Project, helped with research. The manuscript benefited greatly from comments by Stanford Lalio, Terence Stroh, James Enote, Owen Bobelu, and Roger Jensen.

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Traditional Use of Piñon-Juniper Woodland Resources

Maria Teresa Garcia[1]

Abstract — For generations New Mexicans of American Indian and Hispanic descent have relied upon piñon-juniper woodland resources to satisfy such subsistence needs as food, fuel and building materials. Although this system of resource utilization is based in economics, it also is linked to deeply rooted traditional value systems. These values should be considered in evaluating present conditions and developing proposals for ecosystem management.

INTRODUCTION

Development of a piñon-juniper ecosystem initiative is a direct outgrowth of current Forest Service philosophy regarding its official motto to "care for the land and serve people." This philosophy, as outlined in a June 4, 1992, letter by Forest Service Chief F. Dale Robertson commits the agency to ecology based management for multiple use of land under its jurisdiction.

Ecology is the study of reciprocal relations between organisms and their environments (Hoebel 1972). It is my contention that any valid ecological study must consider the human organism and be concerned with the ways in which humans relate to and affect their surroundings.

The following quotation illustrates the gravity of the situation:

> *"In the current crisis of potential overpopulation with its severe environmental strains, exacerbated by stepped-up industrial exploitation and negative feedback of waste into the environment, human ecology has suddenly become a popular issue, taking on the emotional overtones of a holy war (Hoebel 1972)."*

The fact that this observation was made by an anthropologist twenty years ago and is valid today suggests that the holy war is still on.

For generations, New Mexicans of American Indian and Hispanic descent have relied upon piñon-juniper woodland resources to satisfy such basic subsistence needs as food, fuel and building materials. Although this system of resource utilization is based in economics, it also is linked to deeply rooted traditional value systems. These values should be considered in evaluating present conditions and developing proposals for ecosystem management. The purpose of this presentation is to identify specific past and continuing use of the piñon-juniper woodlands by traditional peoples; to suggest that although we all live in the same world, we view it differently; and to advocate the need for recognizing and valuing traditional lifeways in making management decisions.

At the risk of generalizing and within the constraints of this symposium format, I will attempt to contrast American Indian and Hispanic world views, including human ecology, with those of dominant or mainstream U.S. society. These remarks should be taken as applicable to Hispanics of New Mexico, Pueblo groups in general, the Navajo and the Jicarilla Apache living in the area of the Colorado Plateau and the New Mexico Rocky Mountain and Rio Grande region.

WORLD VIEW AND HUMAN ECOLOGY

Anthropologists define world view as the cognitive view of life and the total environment which an individual or members of a particular society or group hold (Hoebel 1972). World view is so ingrained in each of us that, on a daily basis, we make observations and judgments we simply assume are immediately intelligible to others.

As an example, I recently attended a meeting where the phrase "return the area to pre-settlement conditions" was used. As an archeologist and as a Hispanic, my immediate reaction to this wording was, "Whose settlement? Humans, in general, American Indians, the Spanish, or more recent Euroamericans?" In this case, the reference point in time was the turn of the century. From my personal perspective, I would categorize this as the recent past when you consider the archeological record documents human use of the area dating back thousands of

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years. While the speaker and I may have had the same physical landscape in mind, our world views created vastly different perceptions of it.

Cultures, like ecosystems, are dynamic entities. Contemporary American Indians and Hispanics are neither frozen in time nor relics of an idealized past. They are modern peoples who, in spite of formidable odds, reflect the principle of cultural continuity. That is, they retain certain common traits by which they can be identified as distinct cultural groups when considered within the context of modern U.S. culture. These common traits include observable behavioral patterns and norms related to such aspects of life as language, religion, kinship, social organization, and subsistence patterns. Characterization of these traits as "traditional" indicates they derive from each group's historic past.

Prior to the arrival of the Spanish in New Mexico, American Indians had developed complex economic systems in response to their physical and cultural needs. The archeological and ethnographic records document substantial information about their settlements, technology and material culture, tool manufacture and use, religion, techniques of food extraction and production, diet, and social organization. Given population estimates and distributions at the time of contact, it is safe to characterize their ecological adaptation as successful rather than marginal.

The piñon-juniper woodland is an example of what can be called a micro-environment within the Southwestern environmental setting. For prehistoric and historic peoples, it was viewed as a storehouse of resources dominated by piñon and juniper species but also included various species of shrubs, herbs, grasses, roots, tubers, berries and large and small game. These resources were used to meet personal and group needs ranging from food, fuel and building materials to tools, clothing, and medicine. American Indian world view fostered then, as it does now, a holistic sense of place and reliance upon one's surroundings. More important, it ascribed little difference between people and the natural world (Bane 1990).

This perception is embodied in Robert Lake's (1990) writing on the Law of Reciprocity: "By following the Law of Reciprocity, we will receive the energy, spirit, and power of the thing we harvest and use; not just its physical part. Life is a reciprocal relationship.

We have a mutual dependence upon each other for survival, and we should always remember that in our dealings with our relations in Nature, the Spirits, the Great Creator, and each other...that it is an exchange of privileges."

In addition to this precept, American Indian views on landholding also are relevant to this discussion. Throughout the Southwest, concepts of land tenure varied to some extent from group to group, but in general, all Pueblos, the Navajo and the Jicarilla Apache recognized various forms of what we would term private ownership of agricultural lands (Jorgensen 1983). Ownership might be vested in individuals, clans or extended families, but there was a mechanism for establishing and delimiting personal space. Access to hunting and gathering areas, such as the piñon-juniper woodland, on the other hand, was communal or influenced by what has been called a communitarian ethic (Jorgensen 1983). This ethic prescribed that individuals organized into a unit, such as a pueblo or tribe, shared or used available resources within certain territorial limits.

The ramifications of the Spaniards' arrival in the New World were debated at length during 1992 and are not an issue here. Rather, the focus is on the cultural legacy that has survived since contact with native peoples and the reality that combination of American Indian and Spanish traits has contributed the primary components to what we identify as contemporary Southwestern culture. Further, it is significant that despite the fact the Spanish came from what has been described as a world of "...patron-client social relations, material wealth, iron tools, food markets, domesticated animals, Aristotelian logic and divine right (Ford 1987)," they shared with American Indians a deep respect for land and water and held similar notions regarding land tenure.

Alongside the original inhabitants of this region, the Spanish devised a subsistence pattern or ecological adaptation suitable to their newly adopted home. What developed as the traditional Hispanic land ownership system in New Mexico has been characterized as:

"...in many respects the reverse of the Anglo-American system. It included both individual and community land grants, the latter being the most common form in northern New Mexico. ... The community land tenure system was not a fee simple system; rather it centered on private agricultural landholding, encumbered by various collective constraints, and communal pasturage and woodlands with individual rights of usufruct (Van Ness and Van Ness 1980)."

Usufruct is a legal term and can be defined as the individual's right to utilize and enjoy the benefits and advantages of something belonging to another or all, such as the woodlands, as long as the use is judicious. This practice is in direct contrast to the medieval English system whereby the King owned and controlled all resources in the forest. Access to these resources was restricted by the sovreign, and landless peasants were not allowed to cut trees or harvest game. Violation of these restrictions was dealt with by severe penalties.

Thus, because their world view was more similar to that of American Indians, Spanish settlers of New Mexico developed a similar economy based on what they could produce on private agricultural lands coupled with what they could obtain from the surrounding environment.

By the turn of the century or "pre-settlement times," both American Indians and Hispanics had become part of a larger, more diverse population in New Mexico. In response and as part of the natural selection process, both groups attempted to adjust to changed conditions and circumstances. Among the most dramatic changes were a permitting process for obtaining resources and grazing, and large scale, commercial harvesting of forest commodities from what they both considered ancestral

lands. Wage labor in the mining, timber and grazing industries also became a option. People who for generations had been essentially self-sufficient, and had used barter as a means of obtaining products and services were drawn into a market economy. Social and technological change continued to be introduced into their environment, yet many American Indians and Hispanics choose to live in culturally prescribed ways: retaining what land is still theirs; farming family plots; gathering wood for heating and cooking; grazing family herds;hunting and gathering in the woodlands each year to supplement their diet, prepare traditional foods and obtain materials for producing secular and ritual objects.

This is a subsistence pattern that persists today. It is a circular, experiential pattern of living rather than one learned by taking part in Earth Day activities or earning a degree in Environmental Education. It is a deeply rooted pattern held in high esteem by its practitioners. Finally, it is a pattern that effectively integrates traditional peoples' articulation between their social and natural environments.

CONCLUSIONS

In conclusion, the relationship between traditional peoples cultures and their environment must be considered as we pursue strategies for sustainable stewardship of the piñon-juniper woodlands. The wants and needs of these people must be examined in terms of personal and special uses, economic opportunities, recreational activities, and spiritual values. These wants and needs, in turn, must be balanced with concern for the physical and biological dimensions of the ecosystem. Failure to do so would be nothing less than environmental ethnocentrism whereby traditional ecology is judged according to the practices and standards of non-traditional people or the hard sciences. It is presumptuous to assume that meeting these wants and needs correlates with irresponsible behavior or conspicuous consumption of resources. For example, the cutting and burning of green piñon was not an historic practice. It is a more recent phenomenon that has increased with use of the chainsaw and in proportion to population growth in the Santa Fe and Albuquerque areas. It is a small scale, quick cash pursuit in reaction to modern preference. And, for this reason, it is a practice easily modified particularly if replaced by an alternate economic opportunity. People are part of the ecosystem. Exploring and understanding the human dimension in ecosystem management is a challenge we must accept if we are to be sincere in our intent to formulate and make sound management decisions.

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The Sociological and Ecological Consequences of Managing Piñon Woodlands

William deBuys[1]

In the program, the title for this presentation is "The sociological and ecological consequences of managing piñon woodlands," but I think I had better correct that. While I very much want to know what those consequences might be, I must confess I don't, and I seriously doubt whether anybody does. Certainly the history of the piñon woodlands shows we have not understood them yet.

What I'd rather do than speculate about consequences is to talk about the point of view one might adopt in approaching the woodlands and in becoming a student of those consequences. Whether you are a manager, researcher, or user of woodland resources, the perspective from which you approach your work will be vital to whatever success you ultimately enjoy: so let's talk about perspective.

Often these days when we discuss piñon we talk about the need to restore the health of an ecological system that has suffered from human activities. Clearly, restoration is a major theme of this conference, and it is important not least because a healthy piñon-juniper community can provide valuable benefits and support considerable human use provided that use does not exceed the ecological limits of the resource. A fine writer of a decade or so ago, Rene Dubos, stated in his final book, The Wooing of Earth, that "the recycling of degraded environments is one of the most urgent tasks of our age." I suspect that most of the people involved in this conference would agree with that proposition in regard to the piñon-juniper woodlands of the Southwest.

To the extent we are involved in the rehabilitation -- the healing -- of the land, we are all, in a way, doctors and therapists. What I would like to suggest is that as we approach our work of healing like doctors, by first taking the hippocratic oath. It tells us, "First, do no harm." Unfortunately, this is not as easy as it sounds. Environmental history, like the history of medicine, provides many examples of cures that were worse than the disease they were supposed to correct. For example, land managers early in this century conceived of a grand way to stabilize eroding river channels, stream banks and hillsides. With enthusiasm they imported a hardy and all-but-indestructible tree from Asia and planted it in those erosion-prone areas. In many cases the tree accomplished its mission of stabilization, and it certainly flourished.

It has since spread through the west like a prairie fire and has become the dominant vegetation along many southwestern watercourses, where it out-competes our native cottonwood and willow vegetation. As you know, I am speaking of salt cedar or tamarisk, which today is the bane of southwestern riparian communities and ranks one of the most pernicious and problematic plants in the region.

If only the importers of tamarisk had thought more broadly and conservatively about what they intended to do. If only they had resolved, "First, do no harm."

There are many other examples of this kind. In every case they illustrate that people rarely can predict the full range of the consequences of their actions. Therefore we must resolve, all the more emphatically, "First, do no harm."

This is particularly important for federal land managers. I have worked closely with people in the Forest Service and BLM and have high regard for both agencies. Generally speaking, however, these folks remain in a given post only a few years and then move on. As a result, very few of them stay in place long enough to see any but the earliest effects of what they do. They escape having to live with the consequences of their actions.

Worse, it is exactly because their time is limited that they often feel obliged to get maximum results as soon as possible. They get paid for doing things. So they do as much as they can.

Most of us are effective at persuading ourselves that the good of our work is as good as our intentions. Unfortunately this almost never the case. In fact, I submit to you that outside of catastrophic outbreaks of evil, like that presently afflicting the former Yugoslavia, good intentions produce as much damage to land and society as bad intentions do. Let me give you an example of this with regard to piñon-juniper woodlands. The fuelwood co-ops on the Carson and Santa Fe National Forests in the late 60's and early 70's grew out of the very best of intentions. The National Forests played midwife to these programs which also received support, I believe, from the Office of Economic Opportunity, the lead agency waging the "War on Poverty."

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The idea was to bring land-based economic activity to poor, rural communities whose people had very little access to good-paying cash jobs. The need for such help had been amply dramatized by the Alianza's so-called "Courthouse Raid" in Tierra Amarilla. It so happened that the inception of the wood co-ops also coincided with the new availability of affordable gasoline-powered chainsaws and four-wheel-drive trucks. The co-ops and these new tools enabled local people to harvest piñon and juniper wood and market it collectively So folks went out and cut literally thousands of cords of green piñon and juniper and loaded the wood on trucks and semi's, and those truckloads were hauled to urban centers like Denver, Colorado Springs, and Albuquerque.

The program produced some good short-term employment for people in rural communities, and the value of the cash they earned was great--it repaired the roof, built the bathroom, paid for mother's operation, maybe paid for a child's education. These were important benefits. But the negative effects of the program were perhaps greater, and their consequences more enduring. In cutting those thousands of cords no thought was given to the effects on the land: no thought was given to the obvious high grading of the piñon juniper stands, as only the largest trees, the ones biggest and quickest to cut and load were taken: no thought to the vast numbers of new roads and truck trails that were developed: no thought of consequences on soil disturbance and not even any thought of the availability of future fuel wood supplies for the people who live in the local area, the very people who were cutting the wood for coop and who were cutting their own future wood supply and selling it to people who would not need it nearly as bad as they themselves would over the long haul.

The wood coop faded away often as a result of management problems and increasing inertia and as the result also of the fact that easy wood was harvested and sold. Even so, heavy use of PJ woodlands continued. The oil shocks of the early 70's, which drove up the price of propane, played a role, as did the ever more widespread availability of chainsaws and four-wheel-drives. People tended to select only the trunks of trees leaving behind the branches, but it used to be the other way around. People used to go into the woods with wagons and cut just the branches-leaving the trunks alive and healthy, and continuing to grow. The old way was fundamentally sustainable: the new was devastating.

In about 1976 I became interested in the management of the piñon juniper woodlands as a result of buying a horse. I rode that horse everywhere and saw a lot of country around the village where I lived south of Penasco. Everywhere I went I saw the stumps of freshly slaughtered piñon and juniper trees, and I would see branches and tops, representing a lot of perfectly good fuel wood, lying on the ground

Along with Jeff Kline and Juan Lopez from the neighboring village of Las Trampas, I became very concerned about the progressive devastation of the woodlands. We spoke with staff of the ranger district and asked two questions: do you know with some level of assurance how much annual growth of fuel wood, that is to say of green piñon and juniper, occur on the district' And secondly, do you know how much piñon and juniper is being removed from the district each year? We figured the answers to these questions would provide the starting point for managing the woodlands for sustained yield. We had been told that in the land of many uses everything was managed for sustained yield.

Unfortunately the Forest Service managers had no idea what the answer to either question might be. We pressured them to find out and they did some sampling here and there to count the number of piñon stems per acre: then they calculated how many piñon acres they had: then they subtracted the slopes over 30% and after crunching the numbers came up with an estimated yield of 250 cords per year--for the entire Penasco Ranger District of Carson National Forest.

As to how many cords of wood were actually being cut, nobody ventured a guess, but there was a box at the ranger station filled with stubs from all the fuel wood permits that had been issued in 1976. Nobody had ever bothered to tally them. We asked permission to do so, and permission was granted. Our count showed that 1,700 cords had been permitted to be harvested in 1976--against the growth of about 250 cords. Think about that. Sound's like a program for the liquidating of a resource. And probably the situation was worse than the figure indicate. The growth rates assumed for piñon were probably high, and the cut was probably greater than the permits indicated because many woodcutters didn't bother to get a permit. Even if you got a permit for 3 cords, did you stop at 3 or did you really get 4?

In any event, we had a great imbalance. Another thing we learned from our permit tally was that about 95% of the permits were issued to people from villages within the boundaries of the ranger district. In other words, there was little truth to the widespread idea that "outsiders" were mainly at fault for over-harvesting.

The great thing about the Forest Service was that, once good data was available, it acted. Chuck Bazan was the District Ranger and he initiated a series of public meetings in villages on the district to discuss the piñon situation. Those public meetings were an example of the Forest Service at it's very best. As with most public meetings, there was a lot of griping, but Bazan and his team handled it well. People said, if things are this bad, why didn't you start doing things about it sooner-why didn't you begin regulating this? Why didn't you begin some controls? Veterans of the Forest Service's range program appreciated some of the irony of the situation because they had been working to establish appropriate controls on range use for decades--and without local support. But irony aside, at the meetings on fuel wood harvest, the people did an amazing thing. They accepted the information they were given, and said they were willing to change their use of the woodlands.

The Forest Service presented alternatives: there could be a lottery for a limited number of permits: permits could be distributed on a first-come-first-served basis: the Forest Service, or a community committee might try to prioritize neediness

among the aged, the poor, etc. The people gave a clear answer. They said they didn't want to prioritize or have lottery or adopt a system of any kind. They said that if everybody could not have equal access to green fuelwood, then nobody should. Let's just shut the whole thing down, they said, let's stop cutting green piñon and juniper stove wood. And that is what happened. Not long ago I talked with a friend who used to work in the wood co-ops. He spoke of those days with deep regret. "We all thought it was the right thing to do," he said, "but look at what we lost: nut harvest, game habitat, erosion, wood for the future."

As managers, as people who would heal the land, we need to approach our work with a deep sense of humility. We know predicted models are almost never right. A recent article in the journal Science [April, 1993] questions whether science is capable of building reliable models for sustained yield--the authors say it has never done so in the past. The obstacles are many: models never adequately accommodate the natural variability of ecosystems: still less do they allow for the influence of rarely accommodate human greed and avarice.

I'd like to suggest that we not put all our faith in science but learn to depend more on our own moral fiber. I would like to suggest that as we try to rehabilitate the piñon-juniper woodlands, we first ask ourselves, what are our blind spots? What are we missing;? What are we not taking into account?

We can never answer these questions fully but we may get some thoughts, some conservatism, some humility. Our blind spots are almost always manifold but they are almost never manifest. We need to seek them diligently so that first, we do no harm.

Further, I submit, we should subject all projects to the following test--especially if we will not be around to see the consequences. We should ask, would I do this on my own land? Would I use my own money to do it? Will I be able to live with consequences of these actions if they turn out differently from what I now predict? Would I be willing freely and openly to accept responsibility for those consequences? If the answer to all those questions is yes, then that will be a program we will all want to applaud.

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Establishing Research, Management, and Harvest Areas for Piñon Nut Production

Gary Cunningham[1], Jim Fisher[2], and John Mexal[3]

Gary Cunningham...

New Mexico State University's Agricultural Experiment Station, like most agricultural experiment stations in the United States, has been around since 1888. This is our second century. Some people think we are an outmoded institution. I prefer to think that we are venerable.

The word productivity might best describe the focus of much research at agricultural experiment stations during their first century. This focus included increasing production of agricultural systems, as well as non-agricultural natural ecosystems.

But for the second century, I think sustainability is the word that describes our focus. While the first century of agricultural experiment stations did include research on maintaining sustainability, I think this is becoming a greater emphasis today.

I also think agricultural experiment stations, especially New Mexico's Agricultural Experiment Station, will turn more attention to natural resource systems — that is natural ecosystems. These systems are not untouched by man. But they have been less influenced than those systems which have been heavily managed for a single resource.

The first century's emphasis on production taught us that when we manage a system to maximize production of a single resource, we make serious mistakes for long-term sustainability of that natural resource.

We need to keep this in mind as we think about changing management of piñon-juniper research systems in New Mexico. We shouldn't lose our sense of the ecosystem. Pinon-juniper systems are not just sources of piñon nuts; they're also sources of clean water, fresh air and wildlife habitat. They're reservoirs of biodiversity and areas of scenic beauty. All of these things are of great value. We can not manage in an effort to maximize any one resource, if we really hope to sustain the entire ecosystem.

When we talk about ecosystems, we aren't simply talking about numerous organisms assembled at a particular place and time. We are talking about energy flow and nutrient cycling — those important ecosystem characteristics that serve mankind.

I want to emphasize that the Agricultural Experiment Station researchers working on piñon-juniper ecosystems never forget the function and sustainability of the whole system. I think this emphasis is of much greater value than only considering a particular commodity. When we consider a commodity like piñon nuts, we are really talking about two systems — one embedded in the other. In other words, we cannot lose sight of the trees for the forest.

NEW VIEWS AND THE NEED FOR WOODLAND RESEARCH

James T. Fisher...

Although piñon-juniper (P-J) woodlands have been studied extensively, we are still far from the point of understanding how they work. Our resource inventories are incomplete and silvicultural treatments have not been sufficiently tested across stand conditions, if they have been tested at all. Also, what appears to be a wealth of research-derived information on this resource is in reality a collection of data amassed from single subject studies. Approaches of this type do not show management impacts on the overall value of this resource. It certainly does not help the manager choose among conflicting uses or products. Now seems the time to direct attention to problems of this type and woodland research areas can offer opportunities to conduct the long-term, interdisciplinary studies needed.

With this said, I would like to put woodland research into a broader context, one that recognizes that our view of nature has changed. Increasingly, we are being told that nature does not behave as a well-oiled machine that works in a fully predictable way in the absence of outside interference. We also hear that in reality nature exists in a balanced, steady state only in the minds of those having a limited view of its complexity and potential for swift change. As our views toward nature change, we are forced to develop new management strategies and this requires

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answering new questions with new knowledge derived from research. The expanding use of terms like new forestry and new ecology suggest this process is well underway.

In an applied sense, wider public acceptance of the view that nature has no balance should ease somewhat the public relations task of the manager. For example, it should become easier to convince advocacy groups that once control is restored to nature a given landscape will not necessarily develop in a predictable manner toward a desired form.

In any case, management will continue to need support from research and in particular the type that assists efforts to evaluate numerous criteria simultaneously. Some variables may be derived from economic concerns while others stem from socio-political issues. Added to these of course is the fundamental issue of asking the right questions to address silvicultural and ecological concerns. In solving problems, the manager may have to examine issues at different scales, as discussed more fully by Allen and Hoekstra (1992). For example, some decisions might be considered at the plant community level. Others might be addressed at the scale of the ecosystem, landscape or management unit.

Time scales are equally important. One assumption might be that nature changes but very slowly as suggested by geological processes or biological evolution. Reality now appears to be that some changes can occur more swiftly than previously thought and managers can benefit when research provides them more reliable estimates of rates of change. Dr. Julio Betancourt's presentation earlier today was particularly impressive in the sense that it shows how rapidly tree populations can expand their geographic range. His work strengthens the view that nature is, at times, subject to swift changes depending on the factors present in a given situation. Most importantly, his work demonstrates how revised rates of change can generate a new list of questions.

Regardless of scale, managers must be provided sufficient information to satisfy the criteria considered in arriving at management decisions. At present, our knowledge of woodlands falls well short of enabling us to meet management criteria, as can be supported by referencing individuals highly respected for their comprehensive knowledge of the woodland resource. In 1986, Dick Basset (1987), for example, reviewed the advantages and disadvantages of even and uneven-aged silvicultural systems while drawing attention to the fact that woodlands have rarely been managed according to silvicultural principles. He concluded that in practice no single system is best for all situations and that more research is needed to test even and uneven-aged silvicultural systems. Milo Larson (1987) similarly identified knowledge voids in discussing the requirements for modeling P-J management. He recommended establishing the relationship between tree stocking and responses of grasses and forbs for major community or habitat types. He also identified the need to establish values for the resources in question. The questions raised by Basset (1987) and Larson (1987) support the view that there is foundational knowledge to be gained by establishing long-term P-J research areas in the Southwest. Such areas would also provide an opportunity to determine how woodlands really work.

Accepting the view that man's presence on the planet has altered nature for millennia, it becomes apparent that management often substitutes for defunct natural constraints (Allen and Hoekstra, 1992). Managers, therefore, must know more than that key factors exist and interact. Informed judgements, will also require knowledge of the strength and direction of those connections. Most importantly, it becomes increasingly critical to know what are the minimum number of measurable connections that can be used to frame a model having predictive value.

In summary, woodland management will be served best by research providing answers to complex problems requiring evaluation of numerous criteria simultaneously. This means the need for interdisciplinary research will continue to rise. Also, we continue to manage P-J in the absence of prescriptions derived from empirical studies. Studies comparing silvicultural systems are therefore, needed and, in some cases, should involve interdisciplinary and long-term efforts to understand how woodlands really work.

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SUSTAINABLE PINON-JUNIPER ECOSYSTEMS OXYMORON OR BLUE-PRINT FOR THE FUTURE

John G. Mexal...

"We really do not understand piñon-juniper ecosystems well enough to manage them." — Dr. J. Betancourt, 1993 Pinon Conf.

"No one knows what the sociological and ecological consequences of managing piñon-juniper ecosystems are." — Dr. W. deBuys, 1993 Pinon Conf.

When one talks of managing the piñon-juniper (P-J) woodlands, I believe we all envision a long-term, multiple use, productive ecosystem, in short, a sustainable ecosystem that includes humans in the equation. In agriculture, a sustainable ecosystem would consist of inputs such as seed, fertilizer, water, chemicals and labor. The output would be money received from the sale of a horticultural, forage, fiber, or grain crop which would allow the ecosystem manager to repeat the cycle. In forestry, a sustainable ecosystem would have inputs of seed or seedlings, fertilizer, chemicals, and labor. The output again would be money generated from the sale of wood and possibly some grazing rights. These ecosystems are sustainable as long as the cost of maintaining the ecosystem (inputs) does not exceed the value received for the products (outputs).

When we envision a P-J ecosystem, we see few inputs but many outputs (Figure 1). Some of the outputs or products are commensurable meaning we can attach value to them and determine the level of inputs needed to make a sustainable ecosystem. Other products are non-commensurable. These products are difficult to value, and thus, may be difficult to sustain given our current level of knowledge. It is also difficult to determine trade-offs between a commensurable commodity such as forage, and a non-commensurable commodity such as scenic beauty.

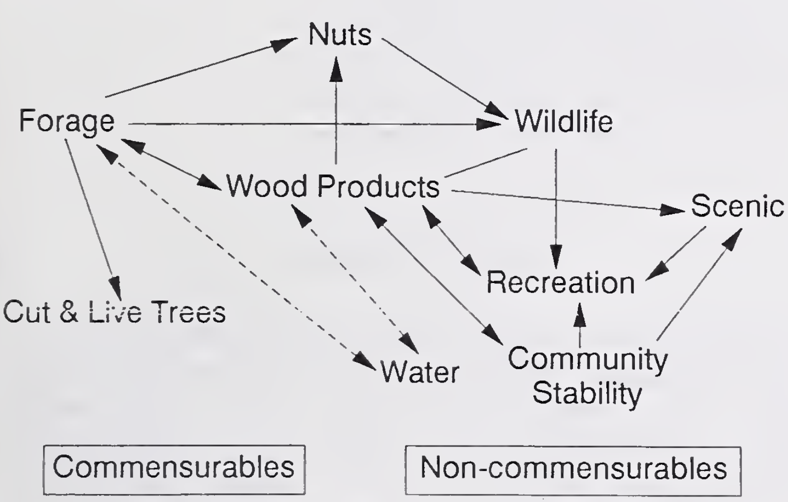

Figure 1. — The P-J ecosystem is a source of many commodities which have both direct (solid) and indirect (dashed) interactions.

There are several approaches to managing a P-J ecosystem. The first approach, which is easiest, is a custodial management system (Figure 2a). This management approach assumes we make no inputs to the ecosystem, and remove the outputs as needed. These are usually commensurable outputs. This approach is disastrous. Using this approach, we have seen the encroachment of shrub or tree species into grasslands, the conversion of P-J to grassland and, often, a loss of non-commensurable commodities. In the figure illustrated, the primary output has been forage. This scenario depicts a lose of forage productivity with a concomitant increase in fiber production. There is also a loss in recreation habitat and horticultural products (nuts and landscape trees). For the sake of simplicity, this scenario assumes no net loss of productivity. That is, the left-hand and right-hand shapes are the same size. The area in each quadrant is different, however. This assumption may be invalid. A loss of net productivity may accompany such shifts in product mix.

The second approach to management would be an economic management system (Figure 2b). This approach would manage the outputs which gave the greatest return on investment (inputs). It is likely, the major commodities would be forage and fiber. Forage would be managed for grazing and encroachment by trees would be regulated by fuelwood harvest. Inputs would tend to be low because the valuation of these two products is low. However, the system would be sustainable and marginally profitable.

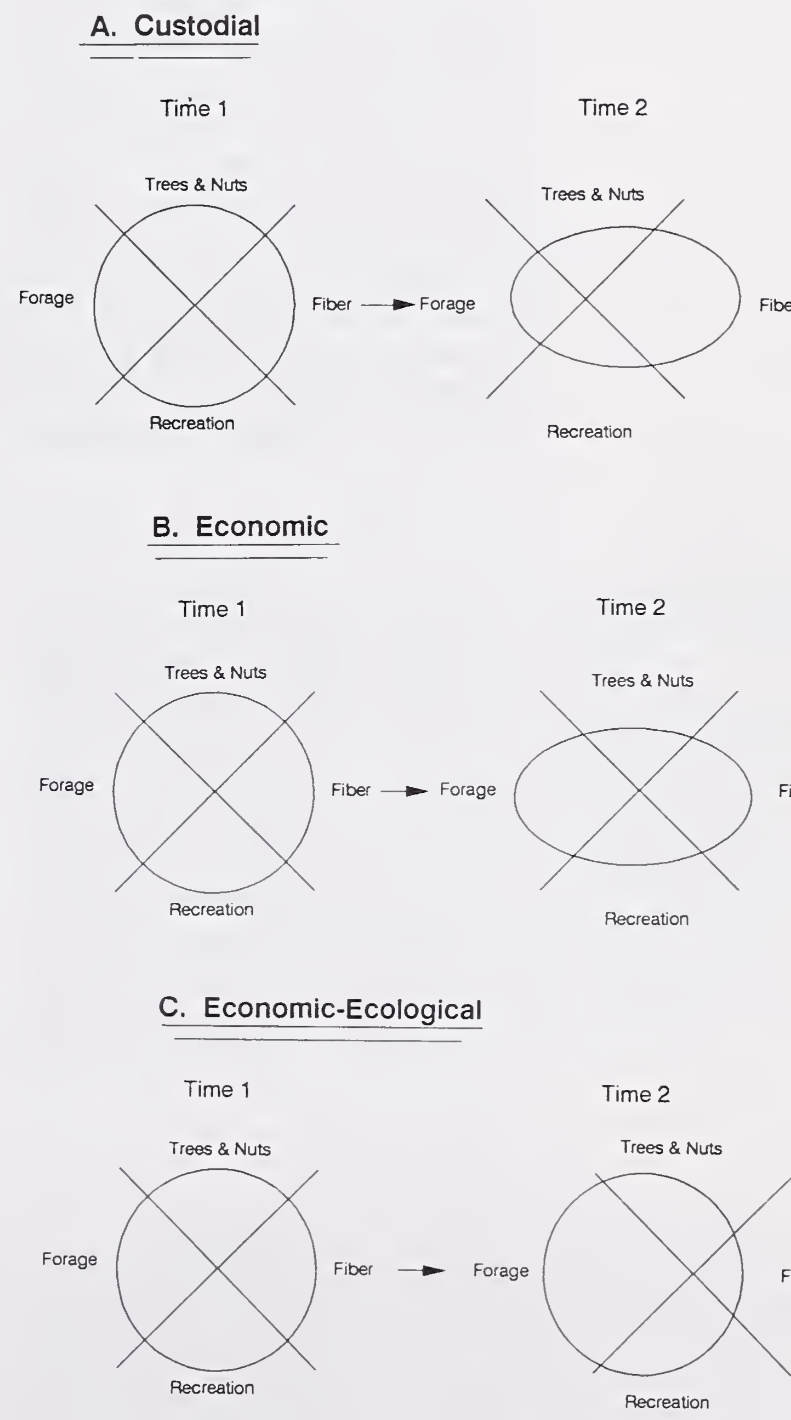

Figure 2. — Idealized examples of P-J ecosystem management.

The third approach would be an economic-ecological approach to management (Figure 2c). This approach would manage the entire ecosystem; taking into consideration both commensurable and non-commensurable outputs. Under this scenario, it is possible the P-J woodlands would become more open with greater shrub and herbaceous cover. This would benefit both livestock and wildlife. Larger tree size would increase nut production. Christmas tree and live tree production would decline, but availability of these outputs exceeds demand by perhaps one thousand fold under custodial management. Recreation and scenic values would increase.

Theoretically, the third approach provides a win-win situation. The P-J woodlands are profitable, sustainable, and enjoyable. In practical terms, it is difficult to institute this management system on an ecosystem as fragile and complex as the P-J woodlands. We lack data on the interactions among the many components of the ecosystem. We lack long-term databases on ecosystem functions, and we lack research sites to test hypotheses and the impact of perturbations. The P-J woodlands will always be an ecosystem in peril until researchers have the resources to develop an understanding of this important facet of our landscape.

Spatial Variation of Piñon-Juniper Woodlands in New Mexico

Rex D. Pieper[1]

Abstract — Piñon-juniper woodlands occupy foothills and areas of intermediate elevations on a variety of soils in New Mexico. Since these woodlands occur in nearly every part of the state, considerable variation in density, species composition and other characteristics is to be expected. Extensive habitat type classification in the Lincoln and Gila National Forests has provided comparative information on coarse levels of spatial variation within these two important areas. Seven habitat types were identified in the Lincoln National Forest and twelve in the Gila. The *Pinus edulis-Juniperus monosperma/Muhlenbergia pauciflora* habitat type occupied the greatest area in the Lincoln National Forest while the *Pinus edulis-Juniperus deppeans/Bouteloua gracilis* habitat type occupied the greatest area in the Gila National Forest. Fine scale variation is also expressed at the stand level where understory species are influenced by the tree overstory canopy. Species composition of these woodlands appear to be related to climate, soils, elevation, past disturbance, geographical location, and other topographic variables.

INTRODUCTION

Piñon-juniper woodlands and savannas occur in nearly all parts of New Mexico except for the extreme southeastern portion (Dick-Peddie 1993). While these woodlands and savannas appear similar in overall appearance, closer inspection reveals considerable variation at both coarse and fine scale levels of resolution. Knowledge of these patterns of variation are important for multiple-use management of these woodlands. The U.S. Forest Service has developed a system of classification for vegetation in the Southwest which offers considerable flexibility and a framework for adding detail as it becomes available (Ferguson 1987). Johnston (1987) has reviewed previous classification systems for piñon-juniper woodlands in the southwest. He includes these woodlands in the Coniferous Woodland Formation and 10 series in the Juniper-Piñon woodland. In the southwest he included the *Pinus edulis* series, the *Pinus edulis-Juniperus deppeana* series and the *Pinus edulis-Juniperus monosperma* series. In addition he listed the *Pinus cembroides-Juniperus* series in the Juniper-Piñon Woodland of the Southwest. Dick-Peddie (1993) included these woodlands in the coniferous and mixed woodlands and juniper savanna where the woodland grades into grassland.

These ways of considering piñon-juniper distribution indicates considerable spatial variation at rather coarse scales of pattern. Since the initial study of Arnold in 1964, smaller scales of patterns have been recognized in relation to areas under crown canopies of the trees and the interspaces. These patterns illustrate small-scale variations within piñon-juniper stands (Armentrout and Pieper 1988, Clary and Morrison 1973, Everett et al. 1983, Jameson 1966, and Schott and Pieper 1985). The objective of this paper is to evaluate these patterns of spatial variation within piñon-juniper stands in New Mexico.

METHODS

Two detailed studies have analyzed habitat types within the piñon-juniper woodlands in New Mexico. These areas are in the Lincoln and Gila National Forests (Hill and Pieper 1992 and Kennedy 1982). Both these studies utilized cluster analysis on data collected from individual, relatively undisturbed stands in both forests to classify similar stands. Principal components

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analysis was used to help identify important controlling factors. The studies on the Gila were more detailed with 92 stands sampled than those on the Lincoln with 39 stands sampled.

Small-scale variation was determined by analysis of understory vegetation under canopies on both *Pinus edulis* and *Juniperus monosperma* in the Lincoln National Forest.

RESULTS

Coarse-Scale Variation

Piñon-juniper vegetation occurs on foothill situations and on level terrain in some locations of New Mexico. The maps presented by Dick-Peddie (1993) show the distribution of the piñon-juniper woodlands and the juniper savanna in the state. At upper elevations these woodlands form ecotones with coniferous forests such as ponderosa pine and mixed conifer forests. At lower elevations, they form ecotones with desert shrubland and grasslands. Nearly all sections of the state are represented by some piñon-juniper vegetation with the exception of the east-central and extreme southeastern portion. The greatest concentration of the type is in the western section, the north-central and the area around the Sacramento Mountains (Dick-Peddie 1993). While most piñon-juniper woodlands appear similar in outward appearance, they vary considerably in species composition of the understory and overstory.

Kennedy (1982) identified elevation, soil texture and the soil water regime as the main factors controlling distribution of piñon-juniper habitats in the Lincoln National Forest. The *Pinus edulis-Juniperus deppeana* habitat type occurred at the highest elevation (average 2400 m) while the *Pinus edulis-Juniperus monosperma/Cercocarpus montanus* habitat occurred at the lowest elevation (average 2000 m) (table 1). Several habitat types were bunched at about 2300 m elevation. Nearly a third of the habitat types sampled in the Lincoln National Forest were in the *Pinus edulis-Juniperus monosperma/Rhus trilobata/Muhlenbergia pauciflora* habitat type followed by the *P. edulis-J. monosperma/Bouteloua gracilis, P. edulis-J. Monosperma/Andropogon gerardii,* and the *P. edulis-Juniperus deppeana* habitat types (table 1). The *P. edulis-J. monosperma-Bouteloua gracilis* habitat type is apparently widespread and was reported for areas in northwestern New Mexico (Francis and Aldon 1983).

Elevation and soil water gradients were apparently not closely related in the Lincoln National Forest since the two habitat types classified at the most xeric occurred at the lowest and highest elevation (table 1).

Habitat types classified as intermediate on a soil water gradient included both *Juniperus monosperma* and *J. deppeana* (table 1, Kennedy 1982) in the overstory. Habitat types listed by Hill and Pieper (1992) for the Gila National Forest show that only one, the *Pinus edulis-Juniperus deppeana/Muhlenbergia dubia* habitat type occurred in both forests (table 2). However, *Pinus edulis* was at least co-dominant on all habitat types in both forests except for several lower elevation areas on the Gila National Forest where *Pinus discolor* occurs. In addition, two juniper species, *J. monosperma* and *J. deppeana,* were the main other co-dominants with *Pinus edulis.* However, *Juniperus monosperma* was restricted to the Lincoln National Forest.

Controlling factors in the Gila National Forest appeared to be somewhat more complex than those for the Lincoln. The habitat types in the Gila National Forest appeared to sort first along a soil water gradient, while aspect, rock and litter cover and latitude appeared to be important factors. While elevation was not identified as an important variable in the PCA analysis, the habitat types could be ranked on their mean elevation with the *Pinus edulis/Cercocarpus montanus/Bromus anomalus* habitat at the highest elevation (2400 m) and the *Pinus edulis-juniperus erythrocarpa/Bouteloua curtipendula* phase *Ceanothus fendleri* at the lowest elevation (1663 m) (table 2). Several habitat types occurred at elevations between 2100 and 2300 m. Thus, the habitat types in the Gila National Forest occurred at the upper elevations comparable to those on the Lincoln, but at much lower elevations. The *Pinus discolor* series also occurs at relatively low elevations in the Gila National Forest (table 2).

The *Pinus edulis-Juniperus depeanna/Bouteloua gracilis* habitat type occurred on nearly 18% of the stands sampled on the Gila National Forest. Several other habitat types occurred on between 10 and 14% of the stands sampled (table 2).

Table 1. — Characteristics of piñon-juniper habitat types in the Lincoln National Forest (from Kennedy 1982).

Habitat Types	Avg. Elevation (m)	Soil Water Regime	Tree Density (No./100 Sq. m)
Pinus edulis-Juniperus monosperma/Cercocarp us montana/Adropogon geradii	2059	Xeric	9.6
Pinus edulis-Juniperus deppeana	2381	Xeric	19.7
Pinus edulis-Juniperus monosperma/Rhus trilobata/Muhlenbergia pauciflora	2157	Intermediate	16.8
Pinus edulis-Juniperus/Bouteloua gracilus	2126	Intermediate	17.3
Pinus edulis-Juniperus monosperma/Bouteloua gracilis	2226	Mesic	32.8
Pinus edulis-Juniperus monosperma/Stipa columbiana	2225	Mesic	43.5
Pinus edulis-Juniperus deppeana/Muhlenbergia dubia	2307	Mesic	28.0

Table 2. — Characteristics of piñon-juniper habitat types in the Lincoln National Forest (from Hill and Pieper 1992).

Habitat Types	Avg. Elevation (m)	Tree Density (No./100 Sq m)	Percent of Area
Pinus edulis-cercocarpus montanus/Bromus anomalus/Ph Quercus ganbellii	2410	4.5	3.2
Pinus edulis-Juniperus deppeana/Bouteloua gracilis	2345	19.0	17.6
Pinus edulis-Juniperus deppeans/Quercus grisea/Lycurus phleoides	2225	6.5	13.2
Pinus edulis-Juniperus deppeana/Muhlenbergia montana	2207	12.6	5.5
Pinus edulis-Juniperus deppeana/Cercocarpus montanus-Quercus grisea/Muhlenbergia montana	2207	8.6	11.0
Pinus edulis-Juniperus deppeana/Quercus grisea/Muhlenbergia dubia	2173	9.1	9.9
Pinus edulis-Juniperus deppeana/Cercocarpus montanus-Quercus grisea/Muhlenbergia emersleyi/Ph Agave parryi	2106	7.1	14.3
Pinus edulis-Juniperus deppeana/Fallugia paradoxal/Lycurus phleoides-Elymus elymoides	2057	5.9	3.3
Pinus edulis-Juniperus depeana/Bouteloua curtipendula1	1983	8.5	4.4
Pinus discolor Quercus grisea/bouteloua curtipendula-B. Hirsuta	1870	6.8	3.3
Pinus discolor-Pinus cembroides/Piptochaetiu m fimbriatum/Ph Quercus arizonica	1820	12.1	4.4
Pinus edulis-Juniperus erythrocarpus/Quercus turbinella/bouteloua curtipendula/Ph Ceanothus fendleri	1663	5.0	5.5

Composition of oak (*Quercus*) species also differs between the two locations. The only important oak species in the Lincoln National Forest was *Quercus undulata* (wavyleaf oak) while several oak species were important in the Gila National Forest (Pieper 1992). These included *Quercus gambelii, Q. arizonica, Q. grisea, Q. turbinella,* and *Q. emoryi.*

FINE-SCALE VARIATION

Piñon-juniper vegetation is characterized by mosaic patterns including the larger trees and their associated understory plants and vegetation in the open interspace areas. These patterns were described by Arnold (1964) for a single one-seed juniper in northern Arizona. He recognized 4 zones around the tree. Clary and Morrison (1973) found that *Juniperus deppeana* trees favored cool-season species beneath their canopies in contrast to areas where the trees were absent. Armentrout and Pieper (1988) described three zones around *Pinus edulis* and *Juniperus monsperma.* Most shrubs were confined to the zone next to tree bole while species under the crown and in the interspaces varied between the two trees species. For example, blue grama (*Bouteloua gracilis)* had the highest basal cover under the canopy of *Pinus edulis* but had the highest basal cover in the interspaces rather than under any canopy position of *Juniperus monosperma* in the Sacramento Mountains.

Some species such as *Piptochaetium fimbriatum, Muhlenbergia emersleyi, Muhlenbergia pauciflora and Lycurus phleoides* often occur mainly under tree canopy. Others may occur more often in the interspaces between trees. Consequently the density and crown closure of the overstory species has a profound influence on understory species. Dense stands may support mostly those species tolerant of canopy position while those species requiring conditions in the interspaces may be limited.

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Isolated Butte and Mesa Summits of the Colorado Plateau

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Abstract — Isolated buttes and mesas are dramatic features of the Colorado Plateau of New Mexico, Arizona, Utah, and Colorado. The isolation of the summits of these landforms is easily recognized. The sites discussed here range in size from 2 to more than 800 ha and support a variety of vegetation types, including piñon-juniper woodland. Most summits are inaccessible to livestock and some native animal species and are rarely visited by people. The most isolated sites support only a small subset of the terrestrial vertebrates that occurs in nonisolated areas.

Biological communities on isolated buttes and mesas have been unaffected by most human activities. For scientists and land managers, these pristine sites could be baselines for gauging impacts occurring elsewhere, define productive potentials of woodlands, constitute sanctuaries for native species, and are important for study of ecological processes.

Pristine or little-disturbed ecological communities are rare in the western United States. Resources of most accessible lands have been used by people for 100s if not 1000s of years. In the piñon-juniper woodland, grazing and browsing by domestic livestock, gathering wood for fuel and building material, off-road vehicle use, human-caused fire, hunting, and physical manipulation such as chaining have altered the woodland. The woodland community we see today does not reflect the presettlement or undisturbed condition. Do we know what the natural characteristics of the piñon-juniper woodland are?

This paper discusses some of the research that has examined the undisturbed communities—including piñon-juniper woodland—on the summits of isolated buttes and mesas in southern Utah.

Monoliths surrounded by cliffs or steep talus aprons with a caprock are prominent desert landforms throughout the Colorado Plateau Ecoregion (fig 1). Buttes are columns whose breadth approximates or is less than the height of the cliffs. Mesas are many times wider than high and have larger summit areas (over 40 ha). Buttes and mesas are not confined to this highly scenic Ecoregion, which includes southern Utah, part of western Colorado, northwestern New Mexico, and a small area of northern Arizona (Omernik 1987). However, they are probably more numerous, varied, and striking there than in other North American or foreign arid zones. Monument Valley on the Navajo Indian Reservation provides abundant popular images of dry buttes. The seclusion of summit areas is readily comprehended and illustrates "natural area" exceedingly well. Scientific or historiographic problems of confidently locating presettlement terrain fragments (Noss 1985) are completely absent.

Buttes and mesas provide superb natural "exclosures" (Laycock 1975). They are inaccessible to one or more domestic or wild animal species that elsewhere influences vegetation and soils. Some summits are only difficult for hikers to reach, while others exclude ungulates and persons on foot. The most isolated sites admit only birds, a few species of small mammals, a sparse herpetofauna and invertebrates. A zoological researcher can select degrees of exclusion represented by a set of summits. Helicopters are often the sole or safest means of access for studies (Johnson 1986) and surveys (Tuhy and MacMahon 1988).

Canyonlands National Park and Glen Canyon National Recreation Area (GCNRA) in southeastern Utah contain the best-studied and most explicated summit environments. The forested mesas of Zion National Park are partly studied, dissimilar, and more humid. Other kinds of cliff geology occur in south-central Utah. Isolated summits of the southern Colorado Plateau (Jameson et al. 1962) are not considered here.

Buttes and mesas have received little mention and consequent action in inventories of geologic natural areas or landmarks (Spicer 1987). This is because the constituent sedimentary strata and their sequences are widely expressed and no known summits have geologic or paleontologic curiosities. About seven mesa tops in southern Utah are established Research Natural Areas

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Figure 1. — Isolated butte in foreground, isolated mesa in right background; 60 km S of Moab, Utah.

and/or Areas of Critical Environmental Concern. Twenty-one summits have been inventoried but not protectively designated yet. At least two undisturbed piñon-juniper woodland communities in New Mexico are designated Research Natural Areas.

The size of most summits under discussion is between 8 and 800 ha. A few mesas are tenuously connected to larger, more accessible uplands by narrow rock peninsulas. Hikers can generally negotiate these causeways, which otherwise bar livestock or motor vehicles.

The primary criterion for "isolation" is the absence of historical and current livestock grazing. Ungrazed sites may also have few and infrequent human visitors, usually range conservationists (Mason and others 1967) or descriptive ecologists (Tuhy and MacMahon 1988). Mule deer (*Odocoileus hemionus*), wild sheep (*Ovis canadensis*) and elk (*Cervus elaphus nelsoni*) have been barred from numerous summits, termed "super-relict" (Tuhy and MacMahon 1988). Furthermore, cliffs may also repel some small mammals and nonavian predators.

Scientific interest in isolated summits began about 55 years ago. Observers wondered if remote promontories of the Grand Canyon rim were "lost worlds" where undescribed species could be living. Such notions where soon dispelled by credible survey parties (Anthony 1937). However, later quantitative work showed that smaller summits do support faunas unlike those of lower terrain or what is termed the accessible "mainland" lying some distance away at comparable elevations (Johnson 1986).

The most thorough and theory-grounded studies are summarized in Johnson (1986:154), who chose faunal groups "that might be affected by the cliff barriers and that significantly influence desert community structure, specifically terrestrial mammals, ants, and reptiles". Study areas were free of livestock or wild ungulates, and were believed to have a reduced suite of rodent and reptile species.

The canyon mouse (*Peromyscus crinitus*) was one of only two mammalian species on one butte. On another butte it was the only species of *Peromyscus*. In these situations, the canyon mouse used a broad range of microhabitats. A "mainland" control site supported at least 16 mammalian species. Mammalian species diversity was inversely correlated with the density of canyon mice. Interspecific competition probably restricted canyon mice to rocky habitats of the mainland. The canyon mouse was the only terrestrial mammal to occur on all the isolated buttes because it is an excellent climber. Most other mammalian species cannot climb cliffs to reach summits (Johnson and Armstrong 1987).

Small-mammal and reptile faunas of the studied buttes and mesas were depauperate in comparison to control tracts of equal area. Reduced species richness was not offset by endemism or the presence of species not living at the base of monoliths or on the "mainlands". Butte-top species are not holdovers from more favorable paleoclimates, stranded above the cliffs.

Johnson (1986) concluded that the list of butte inhabitants was constant, as was the pool of species capable of reaching summits. No island biogeography theory in the extant literature accounted for the observed patterns in southeastern Utah. Instead, buttes were colonized only by certain species, unlike oceanic or lacustrine islands which many species can reach. The airline or surface distance between a butte and the "mainland" has no influence on the size and composition of the summit fauna.

Summits are not rare-animal sanctuaries or evolutionary "hotspots". Summit-dwelling rodents are not morphologically differentiated and no vertebrate species is fully restricted to any

known summit. Faunal richness is less than on the surrounding terrain. Nonetheless, communities of buttes and small mesas are cryptically different from their mainland counterparts. They illustrate a distinct form of natural diversity.

These environments are not genuinely island-like animal or plant habitats. This is true whether they occur in the Ecoregion or elsewhere in the West. The only truly insular, intermontane situations with which buttes and mesas may be poorly compared are rocky islands in the Great Salt Lake of northern Utah. Species richness is closely correlated with lake-island area, and rodent endemism is notably high (Bowers 1982). No comparable species-area relationship nor incidence of subspeciation has been reported for summit animal communities (Johnson 1986).

Buttes and mesa have been used integrally in studies of postsettlement grazing impacts and fire history. Jeffries and Klopatek (1987) used Romana Mesa (GCNRA) in conjunction with three non-relict sites in their study of grazing effects on the blackbrush ecosystem. The mesa had more herbaceous, shrub, microphytic and total vegetal cover than the ostensibly comparable, grazed or once-grazed sites. Jeffries and Klopatek (1987) admittedly could not "control for" the lack of native grazers and browsers on Romana Mesa. Madany and West (1984) contrasted mesa and "mainland" vegetation in light of management and land-use factors that might have altered wildfire return intervals.

Buttes and mesas may be drier, rockier and more depauperate than ostensibly comparable "mainland" tracts of the same size. Their true benchmark value is thereby reduced. The very long-term absence of native browsers can confound comparisons made between ungrazed mesa and grazed "mainland" communities (Jeffries and Klopatek 1987). This raises the serious issues of realism (West 1991) and representativeness (Mackey and others 1988). For reference uses, the main requirement is that study assumptions and site limitations be explicit before extrapolations are made.

Even if buttes and mesas do not genuinely represent the Ecoregional landscape or provide valid management comparisons, they safeguard valuable expressions of dryland environmental quality (West 1991). Regional community classifications are enriched by types—such as piñon-goldenrod—first noticed on and possibly restricted to summits. New associations have surfaced in proportion to search effort, as inventories reach unvisited summits.

The study of butte and mesa environments could help agencies and institutions charged with assessing the overall health of Western ecosystems. The National Park Service (NPS) is considering the Colorado Plateau as a "platform" for detecting climatic-change impacts on the Southwestern parks and kindred drylands. The value of completely pristine, inaccessible places has not been mentioned in global-change literature (Mooney 1991), nor has a supportive role for butte and mesa tops been articulated in operational terms.

For atmospheric changes, pristine summits would enable unambiguous and unconfounded comparison with "mainland" community or species responses. Whereas the disappearance of decimation of a species might be due to anthropogenic factors affecting the "mainland", on a summit it could be more directly attributed to measured ambient warming. All summits discussed here are in federal or joint federal/state ownership, enabling control of access. Ecologists have urged that projects as long as a decade or more get underway on diverse and appropriate sites (Likens 1989). Undisturbed summits surely qualify on many counts.

Ancillary field survey activities on isolated butte and mesa summits of the Ecoregion have included permanent vegetation transects (Tuhy and MacMahon 1988) and repeatable color panoramas obtained over marked ground locations (Schelz and Van Pelt 1990). Both transects and photopoints will enable investigators to obtain comparable data or photographs in the years ahead. Photographic stations could be reoccupied and matching panoramas, stereopairs, or single scenes obtained. Totally undisturbed dryland sites are best documented and analyzed using both photogrammetric and permanent-plot techniques (Turner 1990).

Isolated buttes and mesas provide a set of natural experiments in which natural ecological processes, such as competition, predation, herbivory, and primary production, can be studied at sites that have been little influenced by human activity.

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Pattern and Relationships of Terrestrial Cryptogam Cover in Two Piñon-Juniper Communities in New Mexico

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Abstract — Two relatively undisturbed mesa tops in north central and west central New Mexico were used to study cryptogamic crust ("crust") and associated needle and woody debris, canopy, and vascular plant cover in relation to tree spacing. Four transect length classes were defined using nearest neighbor as the criteria for choosing the transect. At the north central site, soil samples were taken to compare the pH at the soil surface and the soil at 9-12 cm depth from areas with and without crusts. The west central site had a significantly higher grass cover but a significantly lower cryptogam cover than the north central site. However, species of both vascular plants and cryptogams differed between the two sites. At both sites the extent to which debris, and tree canopy, covered an area was inversely correlated with the amount of crust on that area. In addition, spaces opened up by a dead tree on transects (8-12m) between trees had a significantly lower cryptogam cover, without a different degree of grass cover, than similar spaces without the prior influence of a tree canopy. This suggests that areas are only slowly colonized by cryptogams. In some circumstances the presence or absence, as well as the composition, of the crust was correlated to the pH of the soil.

INTRODUCTION

The detrimental effects of grazing (Abatorov, 1990; Brotherson et al., 1983; Nash 1992) and foot traffic (Cole, 1990) on cryptogamic and microphytic soil crusts have gained attention especially in the last ten years (West, 1990). Less documented is the effect of fuel wood harvesting, or logging, activity on cryptogamic crust formation. In addition to mechanical damage done to the soil surface, tree spacing, canopy cover, and debris cover would alter dramatically after wood harvesting activity.

This study is a preliminary survey made at sites having a relatively undisturbed condition (absence of recent grazing and woodcutting) to obtain an estimate of the influence of tree spacing on cryptogamic crust abundance and compare two piñon-juniper communities for the presence and abundance of terrestrial cryptogams along with their association with grasses and forbs. Estimates of cover were made visually, without the aid of a microscope, and therefore represent cryptogamic crust rather than the microphytic soil crust (West, 1990).

SITE DESCRIPTION

Comanche Canyon is being proposed as a Research Natural Area by the USDA Forest Service (Merola, 1992). Largo Mesa is currently under consideration for RNA designation (Dunmire, 1986). Both sites support piñon-juniper woodland with no history of recent fuel wood harvesting or cattle grazing activity. Although the sites differ in proportions of *Pinus edulis* to

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Juniperus monosperma and in the extent of grass cover both belong to the *Pinus edulis/Bouteloua gracilis* (PIED/BOGR) habitat type described in the USDA Forest and Woodland habitat types classification for northern New Mexico and northern Arizona (USFS, 1987).

The site at Comanche Canyon is on a mesa approximately 0.05 km wide x 0.39 km long (Figure 1). The elevation ranged from 2329.3 m at the south western end to 2358.8 m at the north eastern end. On the mesa the soils are very fine and classified as Eutroboralfs, sandy-mixed residuum. Average annual rainfall ranges from 32.3 to 55.6 cm and the snowfall from 35.6 to 101.6 cm depending upon the year. The July average temperature is 22.2 °C The January average temperature at is -2 °C.

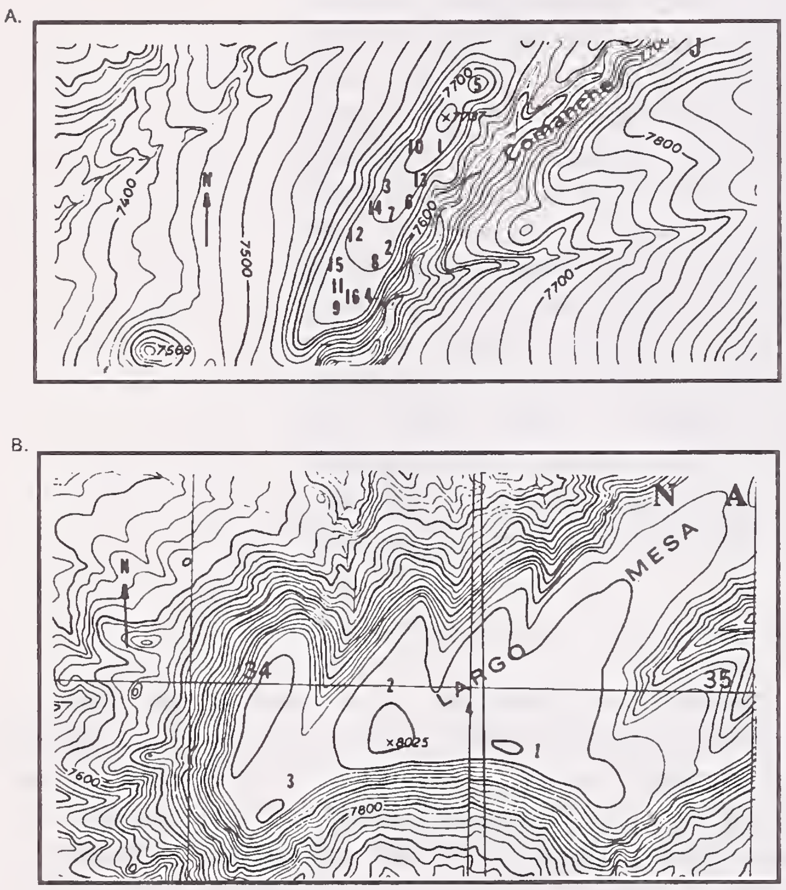

Figure 1. — A. Site plot plan on the mesa at Comanche Canyon. B. Location of plots on Largo Mesa. Plot numbers reflect the order in which the plots were surveyed.

The Largo Mesa site is about 0.62 km x 1.27 km and elevation ranged from 2432.9 m to 2439 m (Figure 2). The soils on Largo Mesa are mainly thin Cerrillos soils over a zone high in lime. Average annual rainfall is 40.6 cm and average annual snowfall is 78.7 cm. The July average temperature is 20 °C. The January average temperature is -1.1 °C.

Because of the lack of disturbance both sites provided an excellent opportunity to study cryptogamic crusts of communities with predominately piñon-juniper overstory.

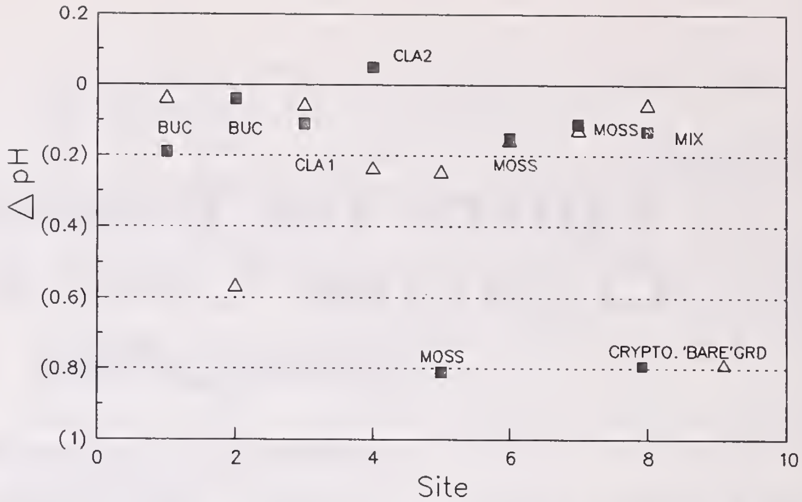

Figure 2. — The differential pH between the soil surface (0-3 cm) and a deeper (9-12 cm) level in 5 different areas, where there was an absence and presence of cryptogamic crust within three feet, at Comanche Canyon.

METHODS

Surveys were carried out in July and August, 1992. Sample plots were determined as follows: A live tree was picked at random. This was denoted as the "central tree" of the sample plot. North, south, east, and west compass bearings were determined and the area divided into quadrants. In each quadrant a line, unobstructed by canopy cover of adjacent trees, was taken to another live tree which was most often the nearest tree to the central tree in the quadrant. This unit of 4 lines was termed a plot.

The length of the line between the central tree and the second tree was measured, and the cover on the transect was recorded to the nearest millimeter. The tape measure, graduated in mm, was placed at ground level for the measurements. The spatial position of cryptogamic crust, vascular plant species, litter, dead trees and bare ground on the line was recorded. Vascular plants and the dominant cryptogams were sampled for future, positive species identification. Estimates of cover were made visually, without the aid of a microscope. Basal and canopy area of grasses (summed together), and canopy area of forbs and shrubs were measured. Litter was classified as either a) woody debris (obvious twigs, pine cones etc) or b) needles debris (needles and fine debris). The presence and degree of decomposition of dead trees on the line was also noted. Canopy cover over the line of the tree at the end of the respective lines was measured. The lichens were classified in the field according to their morphological (foliose, crustose, fruticose) characteristics. Where even this gross delineation could not be madė they were classed as unidentified lichen. There was also a black crust of unknown composition that most likely included more than one species including cyanobacteria and other unicellular algae. This crust was very distinctive and recorded in a separate category (BUC). It may be of similar composition to that referred to by Nash et al. (1977) in their studies of desert cryptogams in the southwestern United States. The crust photographed and described by Williams et al. (1993) was also very similar to the BUC type observed in this study. In the latter case the crust was predominately the cyanobacteria, Microcoleus vaginatis (John D. Williams; personal communication)

In Comanche Canyon there were 16 plots. The line lengths were placed into four classes, 0-3.99 m long (SSH); 4-7.99 m long (MSH); 8-11.99 m long (MLG); and greater than 12 m long (LLG). In each class there were 16 lines. The 16 plots covered the mesa at Comanche Canyon very effectively and their distribution is shown on the map in Figure 1. At Largo Mesa 4 such plots were surveyed, the positions of which are described in Figure 2. The area to the far west was apparently considerably drier than the rest of the mesa and no plots were examined in that region. At Largo Mesa lines between 8-11.99 m long were investigated and thus only compared to lines of the same class size (MLG) at Comanche Canyon. For both sites, the slope of any individual line was usually negligible (%) and at most 4%.

Plant Species Identification

Species of vascular plants and the predominant lichens were identified. Appendix 1 and 2 lists the species of cryptogams and vascular plants found at the plots on the mesa at Largo Mesa and Comanche Canyon respectively.

Soil pH Measurement

At Comanche Canyon paired soil samples were taken at 0-3 cm and 9-12 cm below the soil surface in 5 different areas where there was an absence and presence of cryptogamic crust within three feet. The samples were taken as much as possible from areas of homogenous crust formations. Three to 5 replicates were taken from each site. The cryptogamic crust and the hardened organic crust (neither greater than 0.75 cm) were removed respectively from the soil surface. Two sites were analyzed for the effect of BUC crust on the differential pH. Three sites were analyzed for the effect of a moss crust, two for a fruticose lichen crust which was predominately of a Cladonia species, and one site was analyzed on which the cover was a mix of mosses and lichens. Soil samples were analyzed using a pH meter (Piccolo ATC pHmeter, Hanna, Woonsocket, USA) within 24 hours after collection. Soil was mixed thoroughly with approx 30 ml water and left for 1.5 hours during which time it was frequently agitated. The soil/water slurry was filtered through filter paper (Whatmans #4) and the pH of the filtrate read.

Analysis of the Results

The question of whether tree canopy affects the percentage-cover of microphytic crust was considered by placing the transect lines of different lengths into like classes and testing the variation in percentage-cover among the classes by analysis of variance (ANOVA) after arc-sine transformation of the data. Arc-sine transformation of the data was performed because it is likely that such percentage data has a binomial, rather than a normal, distribution. The cover between trees of a similar length apart (8-11.99 m; classes MLG) were compared between Comanche Canyon and Largo Mesa. The choice of the MLG class for comparison was made on the visual estimation that this was the most common tree spacing at Largo Mesa.

The effect of the presence of a dead tree on the line was also considered using multivariate analysis of variance at both Largo Mesa and Comanche Canyon. Correlation analysis was performed to determine the association between abundance of cryptogams with abundance of forbs, grasses, needle debris, woody debris and pebble cover. Correlation analysis was made on a per line basis, rather than a per class basis, in order to take advantage of the exact line length data collected.

Paired t-tests at the different sites and then ANOVA to include all sites was used to analyze the pH data.

RESULTS

Comanche Canyon

Vascular Plant Distribution

The observation that piñon (*Pinus edulis*) trees far out numbered the junipers (*Juniperus monosperma)* in this stand was reflected in the species frequency among trees chosen to end transects. Of the 128 trees included in the study only 3 were junipers. Representative areas on the whole mesa were examined. Even though the distance between trees, on average, tended to increase from the northern to the southern part of the mesa, lengths of the lines examined were not biased toward any particular area. Variability in the vascular plant species around the mesa may be attributed to slight edaphic and/or climatic differences. For example, Artemisia tridentate was present only around the most southern plot and Cercocarpus montanus, only in mid mesa. There was a trend for the number of forb species, and the frequency with which individual species occurred within 1 m of the transect lines, to increase from the northern to southern end of the mesa but generally there were no other significant variables amongst the species found around the mesa (data not shown).

Opuntia species were to be found all over the mesa but were more prevalent in the southern area and were also in greater abundance on the longest transects. Ipomopsis multiflora was only on the longest transects. This distribution was likely to be a result of the greater amount of light available on the longest lines. Otherwise there were no significant differences among line lengths for the percent cover by forbs (Table 1). Seedling trees (<1' tall) were in evidence (Table 1) on the mesa indicating new tree establishment may be occurring. There were no significant

differences in the percentage grass cover among plots. Neither was there any difference in grass cover, on a percentage basis, between the classes of line lengths.

Table 1. — Means of percent cover on the different classes of transect lines (16 lines per class) at Comanche Canyon

Parameter measured	LLG	MLG	MSH	SSH	Class[1] Probability[2]
Mean length of line (cm)	1478	988	609	272	***
			Mean % of line		
Total microphytic crust	17.36	18.5	14.97	4.44	**
BUC	10.64	10.74	7.47	0.46	***
Algae	0.79	0.00	0.00	0.00	ns
Moss	2.12	1.35	1.25	3.38	ns
Lichen	4.6	6.41	6.25	0.6	*
Saxicolous lichen	0.34	0.21	1.00	0.13	ns
Epiphytic lichen	0.15	0.16	0.19	0.2	ns
Canopy	32.49	38.66	57.82	90.25	***
Woody debris	7.43	8.67	7.85	11.56	ns
Needle debris	38.00	51.2	71.0	95.9	***
Forbs	5.19	4.19	2.71	4.48	ns
Grass	3.10	2.07	1.22	2.41	ns
Cacti	0.24	0.41	0.00	0.00	*
Yucca	0.74	0.12	0.00	5.14	ns
Seedling trees	0.08	0.31	0.02	0.02	ns
Shrubs	0.39	0.00	0.00	0.00	ns
Rock	1.74	2.86	3.06	0.13	ns
Pebbles	0.79	0.73	0.72	0.00	ns

[1] SSH; lines 0-3.99 m, MSH; lines 4-7.99 m, MLG; lines 8-11.99 m, LLG; lines > 12 m.
[2] ns. Not significantly different P > 0.05;
** P < 0.05; ** P < 0.01; *** P < 0.0001*

Cryptogam Cover

There were no significant associations between plot location and total cryptogam cover. There were significant differences in the percent cryptogamic crust between the line length classes (Table 1). The SSH class (0-3.99 m) had the lowest percentage cover by total cryptogams but the highest moss cover. Nostoc (communis) was observed only on 2 lines and those in the LLG class. This may imply that the filamentous blue green favors unshaded sites with little debris (Table 1). As would be expected the canopy covered a much higher percentage (90%) of the line in the SSH class than the other classes (Table 1). A lower percentage of moss, lichen and BUC occurred under the canopy than would be expected if cryptogams were distributed equally along the line, implying that the cryptogams favor areas outside the dense canopy (Table 2). The highest cover was on MLG and LLG lines (Table 1). Lichen cover was much reduced in the SSH class and tended to decline at the longer lengths in the LLG class. On the MSH lines there is a lower percentage outside the canopy than on the longer lines. It may be inferred from this that there are species of cryptogams at Comanche Canyon that favor moderately shady and moist areas as well as those that favor areas outside the canopy with moderate to light debris. As a percentage of the total lichen, crustose lichen was essentially absent on SSH lines whereas on the longer lines it ranged from 5%-9% of the total. In general, crustose lichen are pioneers that are known to favor drier sites.

Table 2. — Proportion of cryptogamic and debris cover on the line that was under the canopy at Comanche Canyon.

Form	LLG[1]	MLG	MSH	SSH	Probability[2]
Canopy (% of line)	32.49	38.66	57.82	90.25	***
% of line under canopy					
Lichen	5.50	7.41	35.45	12.87	*
Moss	19.39	20.21	34.88	25.00	ns
BUC	2.17	2.92	22.4	6.39	ns
Needle debris	81.61	74.11	76.49	92.53	**
Woody debris	44.52	52.42	54.49	91.56	***

[1] SSH; lines 0-3.99 m, MSH; lines 4-7.99 m, MLG; lines 8-11.99 m, LLG; lines 12 m.
[2] ns. Not significantly different P > 0.05;
* P < 0.05; ** P < 0.01; *** P < 0.001

There was a significant negative correlation between total cryptogam cover and the extent to which both the canopy and debris covered the line (Table 3). The negative correlation between needle debris and canopy cover applied only to the lichen and BUC components of the crust, moss did not show such a trend (Table 3). However, it was noted while surveying, that some foliose and fruticose lichens apparently could tolerate some intimate and dense cover by needles under the tree canopies.

Table 3. — Correlation coefficients demonstrating a significant negative correlation between needle debris and lichen and BUC cover.

	Correlation coefficient	P
Needle debris:		
and BUC	-0.60	0.000
and lichen	-0.40	0.006
and moss	+0.02	ns

Pebbles were measured individually on the lines. SSH lines were almost devoid of pebbles and needle debris dominated the lines in this class. There was a positive correlation between the presence of pebbles and lichen and BUC crusts (P<0.01). This is not including saxicolous lichen which were found on the rocks and pebbles to the same extent on all lines (Table 1). One explanation for the tendency for loose pebbly soil to promote crust colonization is that the microtopography would promote small water ways, and also influence dew and frost formation because of significant microclimate modification.

Lichen that favored a wood substrate for growth were found on woody debris. They were a species of Usnea, and from the amount found on the lines they were also equally distributed among the line classes (Table 1).

Soil pH Measurements at Comanche Canyon

There were three cases when the bare ground differed in pH from that with a cryptogamic crust. In one case there was a significantly more negative difference (P=0.01) in the differential pH between bare ground and an adjacent patch of moss (Figure 3). In another case where the crust was predominantly lichen (mostly a species of Cladonia (CLA 2)), there was a mean positive pH differential. At one of the two BUC sites the pH differential of the bare ground was significantly (P=0.01) more negative than that of the soil with BUC.

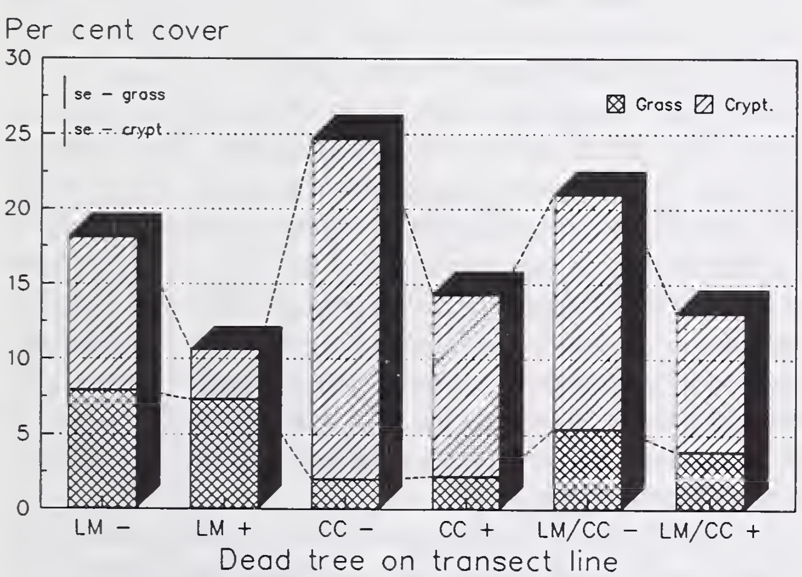

Figure 3. — Graph demonstrating the difference in cryptogamic crust cover on transect lines (8-11.99 m) with the absence (-) and presence (+) of a fallen tree at Largo Mesa (LM) and Comanche Canyon (CC).

If the pH immediately under the soil surface was less than the pH at a depth of 9-12 cm more leaching may have occurred and therefore a more negative differential pH of cryptogam crusted soil compared to "bare soil" could indicate a greater degree of infiltration through the crust. In the case where the pH differential was positive there could either be a surface accumulation of calcareous material (i.e. the surface soil had a higher pH than the deeper soil) or, possibly, there was acidifying microbial actively at the lower depth. Where the pH differential of the bare ground was significantly (P<0.01) more negative than that of the soil with BUC it could be explained if BUC was predominantly algae. Other reports suggest that infiltration maybe reduced through crusts high in algae. The reason for this phenomenon was first suggested by Fritsch (1922) who described the high degree of mucilaginous exudate from terricolous algae. In this situation erosion would probably be reduced under field conditions. The mucilaginous secretion would bind the soil particles together which could reduce wind erosion and water would likely follow the microchannels in the rough BUC encrusted surface, seeping down through the gaps left by incomplete cryptogam cover, and so the sheeting action of water would be unlikely to occur.

Largo Mesa compared to Comanche Canyon

Vascular Plant Cover

Largo Mesa had a much higher ratio of juniper to piñon when compared to Comanche Canyon. Although, not tested statistically, visual observation was supported in our random choice of trees. Five junipers were chosen in the 16 lines surveyed at Largo Mesa, as compared to only 3 junipers in the total 48 lines at Comanche canyon. In addition, at Largo Mesa, one central tree and one tree at the end of a transect were actually two trees growing intimately together, one a juniper and the other a piñon. Only one juniper was represented in the class of line length 8-11.99 m at Comanche Canyon. Grasses were in significantly greater abundance at Largo mesa (Table 4). Bouteloua species (B. gracilis and B. curtipendula) were the most prominent. Opuntia species and seedling trees were absent on and around the transect lines at Largo Mesa, although some

Table 4. — A comparison between the percent cover on the lines (of lengths 8-11.99m only) at Largo Mesa and Comanche Canyon.

Parameter measured	Mean		Probability1
	Largo mesa	Comanche Canyon	
Length of line (cm)	975.9	987.9	ns
% of line:			
Total microphytic crust	8.87	18.5	**
BUC	0.87	10.75	***
Algae	0.24	0.00	**
Moss	1.83	1.35	ns
Lichen	5.93	6.41	ns
Saxicolous lichen	0.55	0.21	ns
Canopy	50.43	38.66	*
Woody debris	7.58	8.69	ns
Needle debris	63.6	51.22	ns
Forbs	1.34	4.19	*
Grass	7.81	2.07	***
Cacti	0.00	0.41	*
Yucca	0.00	0.12	ns
Seedling trees	0.00	0.31	ns
Shrubs	0.00	0.00	—
Scat	0.13	0.18	ns
Rock	0.68	2.86	ns
Pebbles	0.57	0.73	ns

[1] ns. Not significantly different P > 0.05;
* P < 0.05; ** P < 0.01; *** P < 0.0001

Opuntia were observed at other locations on the mesa. The species of vascular plants within 0.5 m each side of the line are described in Appendix 2. Those marked by an asterisk were unique to Largo Mesa as compared to Comanche Canyon. Lupinus kingii and Lotus wrightii were both abundant at Largo Mesa but absent at Comanche Canyon. There were no significant differences between the plots for vascular plant species at Largo Mesa.

One way analysis of variance for the cover on the transect line was analyzed by ANOVA and the results summarized in Table 4.

After arc sine transformation of the data the tree canopy cover was not significantly different from that at Comanche Canyon. Before data transformation, analysis indicated significance existed. As this is a preliminary study this fact should be born in mind. Heights of the trees at the transect ends were similar at both mesas; an average of 5.8 m at Largo Mesa and 5.9 m at Comanche Canyon. From observations made on the growth habit of the trees the greater canopy cover at Largo Mesa was ascribed to the wider tree spacing allowing greater branching of the trees. Between the two locations, the soil was equally pebbly but it was noted that the pebbles at Largo Mesa were, on average, smaller than 1 cm diameter as compared to those at Comanche Canyon which were, on average, larger than 1 cm.

Cryptogamic Cover

Foliose lichen was the morphological type that comprised 44.2% of the total lichen cover at Largo mesa (Table 5). The major foliose lichen was Xanthoparmelia chlorochroa which was absent at the Comanche canyon site. The black microphytic crust (BUC) that was so prevalent at Comanche Canyon comprised only a small portion of the total cryptogamic crust observed at Largo Mesa. However an algal component (in some instances recognizable as a Nostoc species in most others of unidentified species) of the crust was more in evidence at Largo mesa. As these were ocular estimates of crust much of the algae, and all the diatoms and other microscopic components of the crust, at both sites were excluded from consideration in this preliminary study. It could have been that the algae, other than Nostoc, were more identifiable as such at Largo Mesa because of climatic conditions. There was significantly less cryptogamic crust on the line at Largo Mesa than Comanche Canyon (Table 4). They were also other noticable differences between the species present on each mesa. For example, Cladonia chlorophaea was in high abundance at Comanche Canyon but was not noticed at Largo Mesa whereas Diploschistes scruposus was very visible at Largo Mesa and there was very little at Comanche Canyon. The effect of tree species on cryptogamic crust on the line in the 1 m that extended immediately past the canopy was also examined. In the 5 cases where a piñon and juniper were growing together the values were examined in a separate category. No significant differences could be determined (data not shown).

Table 5. — The composition, by morphological type, of the terricolous lichen. (Unidentified lichen was that which was not readily distinguishable as to form and was predominantly associated with BUC.)

Parameter measured	Mean: Largo mesa	Mean: Comanche Canyon	Probability[1]
% terrestrial lichen			
Foliose	44.15	13.32	**
Fruticose	46.36	54.05	ns
Crustose	5.56	9.73	ns
Unidentified	3.93	22.90	*

[1] ns. Not significantly different P > 0.05; * P < 0.05; ** P < 0.01; *** P < 0.0001

Lichens that favored a wood substrate for growth were found on woody debris at Largo Mesa. As at Comanche Canyon some were a species of Usnea. However another, unidentified foliose, type was equally abundant at Largo Mesa.

The effect of a dead tree on the transects were analyzed for Largo Mesa and Comanche Canyon combined. Comparing the two types of line (presence and absence of tree) using pooled data from the two sites there was, using a multifactor analysis, significantly less cryptogamic crust on the lines with a dead tree on them (P=0.017) (Table 4). There were no differences between grass cover on the lines (Table 4). On a per line basis the presence of woody debris is significantly, negatively correlated with lichen cover (correlation coefficient = - 0.4, P = 0.02) but the negative association with BUC was negligible and not statistically significant.

As at Comanche Canyon there was a positive correlation between pebbles and lichen cover (correlation coefficient = 0.4; P=0.025). When considering the MLG transects at both Comanche Canyon and Largo Mesa there was a positive correlation between cover of forbs and cover of BUC (correlation coefficient = 0.65; P = 0.0001) and cover of forbs and total cryptogam cover (correlation coefficient =0.44; p = 0.012) but a negative correlation between total cryptogamic crust and grass (correlation coefficient = - 0.3; P = 0.07). The component of the crust most negatively correlated with grass was BUC (correlation coefficient = - 0.5; P = 0.005).

The proportion of cryptogamic and needle debris cover on the line that was under the canopy was not statistically significantly different on the two mesas. There was significantly (P < 0.05) more woody debris outside the canopy at Comanche canyon.

DISCUSSION AND CONCLUSION

The site at Largo Mesa and Comanche Canyon were significantly different for the species present, and for the percent transect cover, of both vascular plants and cryptogams. Although both were piñon-juniper stands the proportion of piñons to

juniper were different. The marked difference between the species at the two sites may make simple correlations between grass, forbs and terrestrial cryptogams deceptive.

At both sites there was a negative association between percent line cover by the canopy and total cryptogamic crust. This supports the conclusion at Comanche Canyon that close tree spacing lowers crust abundance. However, at Comanche Canyon tree spacing greater than 4 m permitted a substantial cover. Woody debris and needle debris were both negatively associated with certain components of the cryptogamic crust. In addition, at both sites, pebbles were positively associated with cryptogam colonization of adjacent soil. A dead, decaying tree on transects 8-12 m long apparently reduced the cryptogamic cover. This could be due to allelopathic effect from the decaying wood. An alternative explanation for the observation could be that, in general, cryptogams are slow growing and slow to recolonize an area that had suffered the inhibitory effect of a canopy and debris and the disturbance (both within the soil and at the surface) after tree fall. BUC may be composed of early successional species and may be first to recolonize certain areas.

When considering the MLG transects at both mesas there was a positive correlation between cover of forbs and cover of BUC and cover of forbs and total cryptogam cover but a negative correlation between total cryptogamic crust and grass. The component of the crust most negatively correlated with grass was BUC. It seems likely that certain species of cryptogams are influenced by certain species of vascular plant, and/or vice versa (West 1990). It is not a simple relationship, for example, negative correlation between grass seed germination and moss crust (litter) has been observed in a greenhouse study, but in the same study there was stimulation of seedling growth by the same cover 4 weeks after germination (Schlatterer and Tisdale, 1969). Competition for nutrients, water or allelopathic interactions can be hypothesized to account for the phenomenon, but such inferences are beyond the scope of this study. Also, it was noteworthy that there was a higher degree of canopy cover over the lines at Largo mesa which supported the result of a negative correlation between canopy cover and cryptogamic crust at Comanche Canyon. However, due to the differences between sites with respect to vascular plants as well as terrestrial cryptogam species these correlations must be treated cautiously. For example, Cladonia chlorophaea and Ipomopsis multiflora were in high abundance at Comanche Canyon but were not noticed at Largo Mesa, whereas Xanthoparmelia chlorochroa and Lupinus kingii were very visible at Largo Mesa, but they were absent at Comanche Canyon. Also, edaphic and environmental differences at each site must be considered.

Results from this preliminary study on cryptogamic crust and its influence on soil pH suggested that presence or absence of the crust may influence the pH of the soil.

Absence of a microphytic or cryptogamic soil crust is generally understood to lead to an increase in soil erosion (West, 1990). Further studies on a greater number of locations along with examination of tree spacing within the individual locations should be undertaken so that generalizations can be made from the conclusions reached in this study can be made. Namely: Short distances (<4 m) between trees prevent the development of crusts rich in lichens. In some instances areas with abundant grass cover have low cover of certain cryptogams. High forb cover is positively associated with some components of the cryptogamic crust. The extent to which debris covers a line is inversely correlated with the amount of cryptogamic crust on the line but pebbles are positively correlated to high lichen cover. In some circumstances lines opened up by the falling of a tree have a significantly lower cover of cryptogams without a different degree grass cover than lines without the prior influence of a trees canopy.

ACKNOWLEDGMENTS

Financial support for this project was given to the New Mexico Natural Heritage Program by the USDA Forest Service. Field assistance was conscientiously given for this survey by Scott Davis and Philip Tonne.

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APPENDIX 1

Partial list of cryptogams at Largo Mesa and Comanche Canyon.
Most dominant species included:
Lichen:
Xanthoparmelia chlorochroa*
Cladonia chlorophaea**
Cladonia cariosa
Cladonia fimbriata**
Cladonia species unidentified.
Diploschistes scruposus
Peltigera canina
Peltigera aphthosa**
Usnea lapponica (U. sorediifera)
Xanthoparmelia cumberlandia (saxicolous)

Algae:
Nostoc communis

Moss:
Two distinct species (Comanche Canyon).
Three distinct species (Largo Mesa).

* Species marked with an asterisk were not observed at Comanche Canyon
** Species marked with an two asterisks were not observed at Largo Mesa.

APPENDIX 2

Partial list of vascular plant species at Largo Mesa and Comanche Canyon.

Bahia dissecta	Thelypodium wrightii*
Eriogonum jamesii	Descurainia sp.*
Eriogonum alatum	Astragalus sp.*
Cheopodium fremontii	Lotus wrightii*
Gutierrezia sarothrae	Lupinus kingii*
Mirabilis grandiflora	Mirabilis oxybaphoides*
Lesquerella sp	Hedeoma drummondii**
Erysimum capitatum	Lithospermum incisum**
Bahia dissecta	Penstemon linarioides**
Hymenoxys acaulis	Yucca baccata**
Eriogonum jamesii	Opuntia fragilis**
Lepidium montanum	Echinocereus viridiflorus**
Haplopappus gracilis	Ipomopsis multiflora**
Eriogonum alatum	Antenaria marginata
Hymenoxys richardsonii	Hymenopappus newberryii.
Gutierrezia sarothrae	Euphorbia sp.
Erysimum capitatum	Lesquerella rectipes
Chrysopsis sp.	Opuntia sp.
Erigeron flagellaris	Erigeron (divergens)
Bouteloua gracilis	Oryzopsis micrantha*
Aristida sp.	Blepharoneuron tricholepis*
Bouteloua curtipendula	Koeleria cristata
Hilaria jamesii	Sitanion hystrix

* Species marked with an asterisk were not observed at Comanche Canyon
** Species marked with an two asterisks were not observed at Largo Mesa.

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Managing Southwestern Piñon-Juniper Woodlands: The Past Half Century and the Future

Elbert L. Little, Jr.[1]

Abstract — The dominant species in southwestern piñon-juniper woodlands is piñon or twoleaf piñon (*Pinus edulis* Engelm.). Though productivity is low because of low precipitation, this type is very important because of its vast acreage and increasing demands. A great change in management during the 1950's and 1960's was eradication of trees on several million acres. Subjects of high priority among the research needs for managing southwestern piñon-juniper woodlands include: preparation of a new bibliography; a new forest survey or inventory; annual piñon nut forecasts; establishment of small piñon arboretums or orchards; a new economic analysis; harvesting piñon nuts; shelling piñon nuts; and marketing piñon nuts.

The lively discussion on research needs suitably ended this Symposium. Interested persons can look forward to additional symposia and the valuable volumes with summaries of current research. I wish to share my unique opportunity to observe piñon-juniper woodlands in southwestern United States for more than a half century, after four years of basic field research there (1937-41). Several subjects of high priority among the many research needs proposed at the Symposium will be discussed here. This article follows mine at the 1991 Symposium (Little, 1991).

The dominant species in the piñon-juniper woodland of New Mexico and Arizona, piñon or twoleaf piñon (*Pinus edulis* Engelm.) is associated with four species of juniper (*Juniperus*). In the Great Basin of Utah, Nevada, and eastern and southern California, singleleaf piñon (*Pinus monophylla* Torr. & Frém.) is dominant. This marginal woodland of small evergreen conifers occupies an altitudinal climatic zone below the commercial humid forests of pines and other conifers in high mountains and the semiarid grasslands and shrub vegetation of low plains. The term juniper-piñon woodland is also appropriate, because junipers extend beyond piñons to great expanses in the Northwest. These two distinct species are the only pine species native in the United States that are commercially important for their edible seeds. They differ in forest management as well as in nuts commercially, such as size, shell thickness, and taste. The small nut of *Pinus edulis* high in oil content produces a taste suggesting bacon when toasted and is preferred by most persons to the mealy nuts of other species. Two to four other species of piñons native in southwestern United States have small ranges and produce no commercial nuts.

This marginal piñon-juniper woodland type is of low productivity because of low precipitation. However, it is very important because of its vast acreage and increasing demands from expanding local populations. Under multiple use, piñon nuts are a valuable renewable natural resource.

"Managing woodlands for piñon nuts" was the title of a botanical note published more than a half century ago (Little, 1941). Progress has been slow. During and soon after World War II, piñon nut harvests declined somewhat, apparently because of shortage of pickers. Eradication of several million acres of woodlands, discussed below, reduced harvests. Now, annual harvests appear to be back to normal.

In the United States, piñon (mostly *Pinus edulis*) is the native nut of greatest economic importance for its harvest from wholly wild trees, Because of low values and high costs, introduction into cultivation of this small tree of slow growth adapted to semiarid regions seems impractical. Piñon should not be compared with pecan (*Carya illinoensis* (Wangenh.) K. Koch), another native tree of humid regions widespread in cultivation and even irrigated in southern Arizona. However, slight increase in piñon nut production may be possible through management of wild trees on good sites. Silvicultural treatments include

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thinning by removal of less productive trees, pruning, addition of chemical fertilizers, and control of runoff water through ditches to trees, Possibly, superior tree seedlings could be planted in openings, though commercial nut production may be 75 or more years distant.

Watershed and Air Management is the staff in which piñon-juniper woodlands on National Forests in the Southwest have been placed. The first goal of management of wild lands is soil conservation, including saving topsoil, reduction of accelerated erosion, control of flood waters, and improvement of water quality and yield. I learned this principle in two years (1935-37) of watershed management research at Sierra Ancha Experimental Forest (Parker Creek) on the Tonto National Forest in central Arizona. Much erosion control was accomplished by the Civilian Conservation Corps in the decade beginning in 1933. Some gullies still may need erosion control by rock check dams and piling of brush. Reduction in numbers of livestock may be desirable where grazing is heavy.

The great change in management of piñon-juniper woodlands during the 1950's and 1960's was eradication of trees on several million acres of better sites on the National Forests and other public lands over the Southwest and Great Basin regions (Arnold, Jameson, Reid, 1964). The case against eradication has been summarized by Lanner (1981, Ch. 12). "Broken Treaty at Battle Mountain," the film narrated by Robert Redford and shown at this Symposium, vividly records the destruction of large junipers by chaining. The false, unscientific excuse was that this eradication was "control" of "invasion." However, this woodland is a climatic climax type, and the mature trees destroyed were one or two centuries old, not invaders of grasslands. Two questions are whether this conversion was cost effective and whether it is temporary. Junipers have invaded some areas of grasslands following grazing by domestic livestock. However, reports of invasion by piñons probably refer to reestablishment of piñons in areas cut for mine timbers and fuelwood long ago. Any future proposals for clearcutting and conversion should have thorough review, including preparation of environmental impact statements and approval by conservation groups. Continuing assurance is needed from land managers that some piñon-juniper woodlands will be managed for multiple use including piñon nuts. Further eradication of piñon, New Mexico's state tree, on public lands must not be permitted!

Conversion was the subject of a detailed study by the USDA Forest Service on the Beaver Creek watershed in central Arizona. It was concluded that removal of piñon-juniper did not increase water yield (Clary, Baker, O'Connell, 1974).

The question of fire in management of piñon-juniper woodlands used partly for livestock grazing has been raised in recent years. Generally, fire damage to trees has been minor because of their wide spacing, especially at lower altitudes. No burning (with rare fire outbreaks) usually is preferred over uncontrolled fire. However, at higher altitudes, the tree stands may become dense for forage and piñon nut production. More research is desired to determine whether prescribed burning is practicable on lands managed under multiple use.

A new bibliography or compilation of new references on piñons and junipers is desired, though numerous publications during the past half century are listed in bibliographies and cited in symposium volumes. Three publications available at this Symposium merit special mention. Lanner (1981) has prepared an interesting natural and cultural history of piñon with a detailed bibliography. "Silva of North America" contains chapters on *Pinus edulis* by Ronco (1991) and *Pinus monophylla* by Meeuwig, Budy, and Everett (1991), both with literature cited.

A new forest survey, inventory, or compilation of public lands in the Southwest is needed to determine ownership, composition, areas of potential piñon nut production, present management, and future plans. Areas eradicated and converted into grassland should be mapped as excluded from piñon nut production.

Annual piñon nut forecasts should be published, based on summer surveys of public lands in the Southwest to locate areas with commercial cone crops. These informal surveys to aid pickers began in 1938 were continued for about ten years. There is a commercial crop of piñon nuts somewhere in the Southwest every autumn. The simplest way to increase the harvest is to pay the pickers more. Of lower priority is forecast of cone crops two years in advance by correlation with weather conditions in late summer, the time of formation of earliest microscopic stages (primordia) of cones.

Small arboretums or orchards of piñons and other nut pines should be established in both New Mexico and Arizona to determine the best adapted species and varieties. These could be small groves near ranger stations. The only similar collection of living piñons is at the Institute of Forest Genetics, USDA Forest Service, near Placerville, CA. Those trees have borne cones and have been crossed. (I brought fresh specimens to the Reno Symposium, Jan. 1986.) If I had started similar groves 55 years ago, the trees now would show differences in rate of growth and adaptation.

A new economic analysis of the piñon nut industry is desired. Subjects to be reviewed include fees charged to pickers, methods of harvesting piñon nuts, shelling piñon nuts, marketing including packaging and advertising, and competition from imported nuts.

Harvesting piñon nuts needs further study. At present, the Bureau of Land Management charges pickers a small fee per pound for nuts of singleleaf piñon in the Great Basin region. The USDA Forest Service has no similar fees. Harvesting of *Pinus monophylla* is by closed cones in the trees in early autumn, as illustrated in the film showed at the Symposium, "Broken Treaty at Battle Mountain," narrated by Robert Redford.

Most harvesting of *Pinus edulis* is by individual seeds on the ground with fingers of both hands. At 1 seed a second and up to 1800 seeds in a pound, a person can pick up to 2 pounds an hour where nuts are thick, not including travel time or cost. Harvesting of mature closed cones could be tested during the month of September and perhaps end of August. Incidentally,

these cones are very resinous or sticky, but the resin can be removed with powdered borax mixed with water as needed. During the month of October the cones (with resin) dry and open their scales to shed the seeds by gravity. Then the seeds can be picked from the ground until winter or until harvest by wildlife. *Pinus edulis* has smaller cones than *Pinus monophylla*, with fewer, smaller nuts, roughly 20 to a cone. Most closed cones could be picked with a pruning pole or hook or from a stepladder or longer ladder, though tree climbing could be tried. Raking or sweeping the nuts on the ground into piles could be followed by sifting with a frame of coarse screen, then rescattering of litter. Before the nuts fall, a plastic sheet could be placed on the ground, and then the branches beaten with poles or shaken to release the seeds. (A small truck with bucket lift, suggested in one article, seems impractical on rough ground as well as expensive.) My suggestion is to develop a portable vacuum cleaner to pick up nuts from the ground. A rechargeable battery and a screen to separate out most needle litter and trash would be needed.

A machine for shelling piñon nuts was invented by one dealer in Albuquerque in the 1930's. After the dealer's death, this machine was acquired by another local company. Similar shellers could be adapted from those for other nuts and seeds or for pine nuts in other countries. Some imported nuts may be shelled partly by cheap hand labor. The simplest way to crack nuts of *Pinus edulis* with the teeth or a hammer is by pressure from the ends. The shell collapses and breaks into pieces without damage to the nutmeat. One nut cracker sold for home use has the shape of the letter V and grooves for holding a nut with thumb and finger while pressure is applied. At the 1991 symposium I described and demonstrated the Little Piñon Nutcracker (Little, 1991). It consists of pliers with a block of wood about 3/8-1/2 inch square and about l inch long (or 2 short pencils) fastened within by a rubber band. The nut held between thumb and finger is cracked by pressure from closing jaws f pliers.

Studies in marketing, including packaging and advertising, can be done by specialists in those fields. Piñon nuts, among the smallest of commercial nuts and a wholly wild crop, cannot be produced as cheaply as commercial nut crops. For example, peanuts are harvested in billions of pounds annually, instead of millions, at much lower costs and with government subsidy to growers. Piñon nuts have three main markets: local residents, tourists, and luxury nut stores, such as at airports.

Irregularity of piñon nut crops is a problem in marketing, involving storage and treatment as a commodity to obtain loans and to keep prices stable. As noted before, there is a commercial crop of piñon nuts somewhere in the Southwest every autumn. Also, the simplest way to increase the harvest is to pay the pickers more and thus increase retail prices. However, estimates of the crop not harvested seem high. A light crop is eaten by insects and wildlife ahead of humans. Also, within a few months after maturing, piñon nuts lose about a fifth of their weight in water loss or shrinkage.

"Pine nuts (*Pinus*) imported into the United States" is the subject of my other paper at this symposium. At present, unshelled pine nuts are imported in relatively small quantities. Shelled nuts are imported in increasing quantities about equal to native production. Competition may become serious. Recently in Israel I saw a small plantation of Italian stone pine (*Pinus pinea* L.), the commercial pignolia of subtropical southern Europe, there slightly outside the natural range. The wingless seeds have a thick shell too hard for cracking with the teeth. A sample bought in a nearby town apparently was shelled by hand. The local name from French pignon is pronounced like piñon. Incidentally, Israel no longer tests this pine in forests and has no nuts for export. A new forestry monograph of this species is by two Italians, Agrimi and Ciancio (1992).

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Distribution and Multiresource Management of Piñon-Juniper Woodlands in the Southwestern United States

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Abstract — Piñon-juniper woodlands cover large areas of the western United States and have been at the center of a number of controversies. Woodland stand characteristics vary depending on geography, topography, local site conditions, and general climate. The historical increase in the distribution of woodlands apparently is the result of overgrazing by livestock and the declining role of fire.

Management in the 1950s and 1960s attempted to remove trees from large areas of woodland to improve forage for livestock. The control programs generally were not successful. Multiresource management for sustained production of a variety of products including tree products, forage for livestock, habitat for wildlife species, watershed protection, recreation, and archeological values is gaining support. The most productive sites offer the best potential for multiresource management. Silviculture is a tool for achieving many multiresource goals and for sustaining tree resources. Small, dispersed wildlife openings benefit many wildlife species and livestock. Slash can be manipulated in a number of ways to encourage wildlife or reduce erosion. Single-resource management is still applied to some productive lands but should attempt to create vegetation mosaics or savannahs rather than clear large contiguous areas. Tree control may be easier to justify on low-site lands but other resources must be considered. Proper grazing management is an important key to successful range improvement.

INTRODUCTION

The piñon-juniper woodlands of the western United States have been at the center of several controversies during the past 50 years. Differences of opinion occur between public land managers and users, among the natural resource disciplines, and among managers who began their careers at different times. One controversy concerns the distribution of woodlands prior to European settlement and changes since the introduction of livestock and fire control. This controversy relates to whether woodlands are invading grasslands, or to a lesser extent, drier ponderosa pine (*Pinus ponderosa*) forests. All piñon-juniper stands are not similar; classification of woodlands to recognize differences and similarities is another concern.

Other controversies concern proper management of woodland ecosystems. Should these lands be managed for a single resource, such as forage for livestock production, or managed for sustained production of multiple resource products and amenities? Depending on site and stand conditions, the woodlands can produce variable quantities of fuelwood, piñon nuts, wildlife habitat, forage for livestock, and cover for watershed protection. In addition to these traditional resources, management must also consider increasing recreational demands, threatened and endangered species, and archeological sites. Management goals of the USDA Forest Service and other public land management agencies are to create and maintain a sustaining and healthy ecosystem. However, the agencies, users, private land owners, and Native American communities may

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have different definitions of the desired future condition. Some groups may prefer a landscape containing a minimum of trees while others may prefer undisturbed woodlands or one of a number of intermediate options.

The number of questions and conflicts surrounding management of piñon-juniper lands, as well as the ecological foundations of management, require that all parties reevaluate attitudes toward the woodlands. There is a growing interest and demand for multiresource management that will ensure a healthy and sustainable ecosystem. However, all piñon-juniper sites are not equal; management prescriptions must evaluate the potential of each site. Management decisions must be based on sound scientific information. Unfortunately, our knowledge of the ecology of the woodlands and potential impacts of different management options is incomplete. This paper describes the characteristics and distribution of piñon-juniper woodlands within the southwestern United States and briefly reviews some past and present management options.

PIÑON-JUNIPER STAND CHARACTERISTICS

What are piñon-juniper woodlands? Woodlands consist of trees that are of small stature but more than 16 feet in height, and have relatively open canopies but greater than 40% crown closure (USDA Forest Service 1992). The piñon-juniper woodlands are variable in species composition, density, and in physiographic site characteristics. Some sites contain stands of relatively dense, large trees and meet many of the criteria of old-growth (USDA Forest Service 1990) while other sites contain open stands of mainly younger trees, that appear to be of a more recent origin.

The two-needled Colorado piñon (*Pinus edulis*) is the common species in most piñon-juniper stands in the Southwest as well as in eastern Utah and Colorado. A single-needled piñon whose taxonomic identification is still unclear replaces Colorado piñon south of the Mogollon Rim in Arizona. Another piñon, the three-needled border piñon (*P. discolor*), occurs in southern Arizona and northern Mexico and is usually associated with oak woodlands. Singleleaf piñon (*P. monophylla*) is the most characteristic piñon in the Great Basin areas of Nevada and western Utah. Piñons are commonly between 9 and 35 feet tall and 5 to 18 inches in diameter, although larger individuals can be found on moister sites. The piñons are slow growing but relatively long-lived trees. The older Colorado piñons are often more than 400 years old (Ronco 1990).

Juniper (*Juniperus* spp.) is the other major tree genus occurring in these woodlands. Junipers are generally small, multistemmed trees less than 40 feet high. There are four major juniper species in the Southwest: one-seed juniper (*J. monosperma*); Utah juniper (*J. osteosperma*); alligator juniper (*J. deppeana*); and Rocky Mountain juniper (*J. scopulorum*). Stands may contain one of the juniper species or a combination of species.

Understory biomass within southwestern piñon-juniper stands is generally quite low but because of the wide distribution of the ecosystem, the total number of species associated with the woodlands is great (Medina 1987, Ronco 1990). Important herbaceous species include blue grama (*Bouteloua gracilis*), sideoats grama (*B. curtipendula*), sand bluestem (*Andropogon hallii*), Arizona fescue (*Festuca arizonica*), and goosefoot (*Chenopodium graveolens*). Common trees and shrubs include gray oak (*Quercus grisea*), true mountain-mahogany (*Cercocarpus montanus*), sagebrush (*Artemisia* spp.), and Mexican cliffrose (*Cowania mexicana*). More details on understory vegetation are found in Medina (1987), Ronco (1990), and USDA Forest Service (1987).

SOUTHWESTERN PIÑON-JUNIPER WOODLANDS

Distribution

Approximately 47 million acres of piñon-juniper woodland occur in the United States; it is an important vegetation type in seven of the western states (Evans 1988). The literature contains other estimates of the area occupied by woodlands; many of the differences may be attributed to the way marginal juniper lands are defined. The piñon-juniper woodland ecosystem is particularly important in Arizona and New Mexico. It is the most common vegetation type in the USDA Forest Service's Southwestern Region. About 17 percent of Arizona supports piñon-juniper woodlands (West et al. 1975). A recent survey of forest resources (Conner et al. 1990) indicated that Arizona contains about 9 million acres of piñon-juniper and 2 million acres of relatively pure juniper. The two categories, which account for 56 percent of the total forest area in Arizona, are considered together for this presentation. Approximately 49 percent of the vegetation type is in National Forest and other public ownerships and the rest is on Indian reservations or in other private ownerships (Conner et al. 1990). Piñon-juniper woodlands cover approximately 26% of New Mexico (West et al. 1975). However only 10 million acres or 14% of that state contain stands that can be considered manageable by criteria of density and quality (Fowler et al. 1985).

Climate

In the Southwest, piñon-juniper woodlands occupy the warmest tree-dominated zone. The climate is usually classified as arid or, occasionally, dry subhumid (Ronco 1990). The woodlands grade into grasslands, oak woodlands, and brush-dominated vegetation zones on drier sites and into ponderosa pine forests at higher elevations. Average annual precipitation ranges from 12 to 22 inches and is influenced by geography, elevation, and topography. The seasonal distribution

of precipitation varies depending on prevailing storm patterns; areas in eastern New Mexico receive most of their annual precipitation during the summer, while areas in more northern and western parts of the woodland range in Arizona receive over half of their annual precipitation during the winter (Springfield 1976). Temperature ranges are also variable and may control the upper elevational distribution of the type (Evans 1988). Several systems have been developed to classify piñon-juniper woodlands based on temperature and precipitation (Moir and Carleton 1987, USDA Forest Service 1992).

Soils and Topography

The woodlands generally occur at elevations of 4,500 to 7,500 feet and on all topographic positions. Old-growth stands occur on a variety of physiographic sites. In New Mexico, climax stands are often associated with rocky hillslopes where the sparse understory will not carry fire (Wood and Javed 1992). Woodlands occur on soils that have developed from a variety of parent materials and belong to one of six soil orders (Aridisols, Alfisols, Entisols, Mollisols, Vertisols, and Inceptisols) (Evans 1988). Soils are generally classified as being shallow and well-drained. Woodlands are associated with soils having low fertility (Pieper 1977, Evans 1988), but recent data (USDA Forest Service 1992) indicate that they also can occur on relatively productive soils.

Distribution of Habitat Types

The variability of climatic and site conditions explains the high number of woodland habitat types. Moir and Carleton (1987) recognized at least 70 habitat types and 280 ecological sites in Arizona and New Mexico. Available soil moisture is the most critical factor controlling the distribution of woodlands and composition, density, and stand health in undisturbed sites. Woodlands occur on relatively moist sites that can support dense stands of relatively tall trees and on dry sites where trees are scattered and of low stature. Junipers are more drought tolerant than piñon and tend to predominate on drier sites. The proportion of piñon increases with increased elevation and available moisture until it predominates at about 7,200 feet. Topographic influences are apparent in southern New Mexico where one-seed juniper stands have higher densities on northeastern exposures than on drier southwestern slopes (Pieper and Lymbery 1987). Distribution of Utah juniper in Arizona and northern New Mexico is related to the predominance of winter moisture relative to summer moisture (Springfield 1976). One-seed juniper is most common where winters are cool and dry and where summer precipitation is more important. Alligator juniper and Rocky Mountain juniper are also identified with summer moisture regimes. Rocky Mountain juniper is the least drought-tolerant of the common juniper species and generally occurs above 6,000 feet in northern New Mexico.

INVASION BY PIÑON-JUNIPER WOODLANDS

Distribution of a species is determined by its ecological characteristics that allow it to occupy or re-occupy a site and by successional processes that vary by habitat type (Gottfried 1992a). The dynamics in a site that has supported woodlands for long periods are different than in an ecotonal site. One of the most persistent questions concerning the ecology and management of the piñon-juniper ecosystem is whether woodlands are invading true grasslands to the detriment of rangeland and soil-watershed resources. Fire was the most important natural disturbance in the piñon-juniper woodland ecosystems prior to European settlement. Grass fires maintained some sites as juniper "savannahs" and grassland inclusions because they tended to kill trees less than 3 feet tall (Johnsen 1962). Several successional seres have been proposed to describe woodland vegetation dynamics following fire in the Southwest (Arnold et al. 1964), in Colorado, and in Utah (Evans 1988).

Spanish colonists introduced cattle and other livestock into the woodlands during the 16th century. Two million sheep were in New Mexico by the end of the 18th century (Flores 1992). Livestock numbers increased dramatically in the 1880's as Anglo-Americans began ranching operations throughout the West. There were, for example, 1.25 million cattle and 5 million sheep in New Mexico by 1888 (Flores 1992).

Large herds exceeded the carrying capacity of most ranges and overgrazing was common. The loss of a continuous herbaceous cover had serious consequences. One impact was that fires did not have sufficient fuels to carry through stands and eliminate young trees. Fire control activities also contributed to the decline of fire. In addition to the lack of periodic fire, young trees did not have to compete with grasses and other species for water, nutrients, and light. One-seed juniper seedling growth and survival were greater without competition from blue grama than with it (Johnsen 1962). Grazing and erosion also caused more rapid drying of the surface soils, which tended to favor deep-rooted species rather than grasses and forbs. Livestock also served as carriers for seed and trampled them into the ground. Another impact was that the loss of a protective plant cover led to accelerated erosion. Livestock also tended to concentrate along streams and in meadows, causing further site degradation. The results were increased tree cover in juniper savannahs and an increase in erosion and gullying.

One popular theory holds that woodlands were invading grasslands. Johnsen (1962) did not support the invasion theory. He maintained that many "invaded" grasslands contain old junipers that survived fire and that these areas should be classified as ecotonal juniper "savannahs" rather than grasslands. Older trees survived fires because fire often moved too rapidly to generate lethal levels of heat. Other reasons for their survival include low stand densities and the fact that most tree canopies were too high above a ground fire to be ignited. Johnsen stated that invaded areas were climatically woodlands and that invasion was limited to filling in the savannahs or

grassland inclusions within the woodland type. The lack of fire probably also resulted in an increase in the number of trees in older woodland stands. We may never know if and how vegetation was altered because pre-European vegetation conditions are difficult to document (Gifford 1987).

Paleobotanists believe that the invasion is controlled by climatic fluctuations and that the prehistoric fluctuations in range and density may have been greater than during historic times. The piñon-juniper woodlands, for example, were concentrated south of the Mogollon Rim during the Pleistocene (Lomolino et al. 1989). A northward shift in the summer monsoons would have produced moister conditions favorable to woodland expansion, and the activities of European settlers only provided site conditions that accelerated the process (Neilson 1987).

WOODLAND CONTROL PROGRAMS

Livestock interests have maintained that forage for livestock has declined as the piñon-juniper type has increased in area and density since European settlement. While the invasion question is still being debated; research has demonstrated that total forage production declines as tree crown closure increases (Arnold et al. 1964).

In the period following World War II, management efforts were started to reduce piñon and junipers on western ranges. By 1961, 1.2 million acres of Arizona piñon-juniper lands had been treated using a variety of techniques such as cabling, bulldozing, individual tree burning, grubbing, and chopping (Cotner 1963). The treated sites were usually seeded with grasses once trees were removed. However, the number of acres treated annually in Arizona began to decline by the late 1950s as the availability of productive and easily treated areas declined (Cotner 1963).

The value of piñon-juniper control efforts has been controversial. Arnold and Schroeder (1955) indicated that herbage yields could be increased by removing juniper trees. Clary (1971) also reported increases in understory vegetation following removal of Utah juniper in Arizona; however, yields of seeded exotic grasses declined after 4 to 6 years, while native species tended to increase slowly over time. Seeding was generally unsuccessful in large conversion areas. Successful herbage production following tree removal depended on annual precipitation, pretreatment tree cover, and on pretreatment soil nitrate-nitrogen content (Clary and Jameson 1981). Production also was lower on soils derived from limestone. An increase of between 0.21 and 0.32 AUM per acre was indicated for the most successful projects (Clary et al. 1974). However, the impacts of many treatments have declined over time. In a New Mexico study, Rippel et al. (1983) evaluated a treated area after 20 years, and found that the cover of grasses and forbs was greater in an undisturbed piñon-juniper stand than in the cabled area.

Control programs were also justified by the assumption that they increased water yields. The hypothesis held that replacing comparatively deep-rooted trees with shallower-rooted grasses would result in decreased evapotranspiration and increased runoff, which would eventually reach downstream reservoirs. However, while this mechanism works in vegetation types found on moister sites, the basic moisture requirements on dry sites are similar regardless of vegetation, and one vegetation type is about as efficient as another. Little opportunity exists for streamflow augmentation on warm, dry sites where annual precipitation is less than 18 inches and is exceeded by potential evapotranspiration (Hibbert 1979). Most piñon-juniper woodlands fall into this category. Watershed research in Arizona at Beaver Creek (Clary et al. 1974) and at Corduroy Creek (Collings and Myrick 1966), failed to show significant water yield increases following control treatments. The only experiment to demonstrate an increase (about 0.2 inch) utilized aerial spraying of herbicides and did not allow the immediate harvesting of the dead, standing trees (Baker 1984). However, results from Beaver Creek (Clary et al. 1974) indicated that soils deeper than 12 inches within treated areas retained more soil moisture than did similar soils in untreated areas. This additional moisture would benefit vegetation on the site even if it did not contribute to streamflow.

There is a common belief that the active erosion and gullying observed in the woodlands and the related decline in long-term site productivity are the result of the tree cover and lack of grass (Gifford 1987). However, Gifford (1987) stated: "There is no evidence to support this hypothesis and in fact existing limited research indicates otherwise." Erosion is a natural process but has accelerated because of reduced vegetation cover and overuse of channels and wet areas by livestock. Reduced infiltration is one cause of overland flow and accelerated erosion. Infiltration rates are similar in wooded and chained areas (Evans 1988). Plots with piñon or juniper litter had significantly lower total sediment concentrations and yields than plots with herbaceous cover or bare plots (Bolton and Ward 1992). Interspace areas contributed the most runoff and erosion on the litter plots. However, when the impacts of tree cover and interspace were integrated, sediment delivery was less from a small wooded watershed than from a nonwooded watershed (Heede 1987). Clary et al. (1974) concluded that there were no significant differences in sediment production from treated and untreated watersheds.

It was anticipated that woodland control treatments would benefit wildlife because of increased forage; however, treatment had a neutral effect on mule deer (*Odocoileus hemionus*) (Clary et al. 1974). The deer benefited from increased forage only when adequate hiding cover was available. A study at Fort Bayard, New Mexico (Short et al. 1977) found that large clearings limited deer and elk (*Cervus elaphus*) use because the animals would venture only a short distance away from cover. Because animal use declined as tree density increased, they recommended small clearings interspersed within the stands for improved big game habitat.

The woodlands are considered a nutrient-poor ecosystem. Nutrients can be lost from the ecosystem by chaining and broadcast burning of slash. These activities in singleleaf piñon-Utah juniper stands could result in a loss of approximately

13% of the total ecosystem nitrogen because of nitrogen volatilization (Tiedemann 1987). Assuming that 60 percent of the aboveground total nitrogen would be volatilized (about 764 pounds per acre), and a natural replenishment rate of between 0.9 and 1.8 pounds per acre per year, Tiedemann (1987) estimated that this lost nitrogen would be restored in 428 to 856 years. Such large losses would result in lowered long-term productivity. Other nutrients such as phosphorus are also affected, especially if large amounts of litter are consumed in the burning (DeBano and Klopatek 1988). In addition, burning also has a detrimental effect on soil microorganisms (Klopatek et al. 1990). Covington and DeBano (1990) have reviewed the literature concerning the effects of fire on piñon-juniper soils.

A benefit-cost analysis of control projects using data from throughout the Southwest demonstrated that the most successful projects only broke even (Clary et al. 1974). Fuelwood sales and potential losses in long-term site productivity were not included in these analyses.

MULTIRESOURCE MANAGEMENT

Reevaluation of piñon-juniper management strategies began in the 1970s, partially because of the increase in fuelwood demands resulting from the oil embargoes. Some managers became concerned that the demand for fuelwood could eventually exceed available supplies. The possibilities of sustained production of fuelwood and integrated resource management began to be considered, especially in mature woodland stands. The woodlands provide a full array of products including fuelwood, piñon nuts, fence posts, Christmas trees, forage for livestock, habitat for common and rare and endangered wildlife species, and watershed protection. There has been an increase in the use of woodlands for recreation and for second and primary home sites. The public also has begun to recognize that the piñon-juniper woodlands are connected to the culture and history of many rural and indigenous populations, and that their concerns must be integrated into land management plans. Recognition of the potential value of managing the woodlands for multiple products and benefits was the first step. Managers then had to develop prescriptions that would meet their production goals and still produce or maintain productive and healthy stands. Naturally, sound prescriptions must account for the variability of habitat types and existing stand conditions. Not all sites have the potential to produce the full range of resource benefits, and this factor too must be evaluated. A habitat type classification exists for many piñon-juniper stands in the Southwest (USDA Forest Service 1987), which aids management planning. The classification still needs to be expanded and refined. Management procedures also must be developed that will allow natural resource management without damaging the large number of archeological and historical sites within the woodlands.

The new approach to piñon-juniper management must be based on sound scientific information. However, our knowledge of the ecology of woodlands and impacts of management options is incomplete. The Rocky Mountain Forest and Range Experiment Station of the USDA Forest Service, universities, and personnel from the land management agencies are attempting to fill gaps in our knowledge but the emphasis on woodlands is relatively recent and many questions remain to be answered. The Rocky Mountain Station is currently conducting research on tree regeneration ecology and silviculture; watershed management including soil erosion and site productivity; effects of stand treatments on wildlife habitat relationships; and tree mensuration (Gottfried 1992b).

Management of High-Site Woodlands

A classification based on site productivity can aid management planning. The piñon-juniper woodlands can be divided into high- site and low-site categories based on the potential for growing wood products (Conner et al. 1990). High-site lands can produce wood products on a sustainable basis while low-site lands include areas where volumes are too low to be included in calculations of allowable harvest levels. Some trees can be harvested from low-site lands but they would only support a single entry and the total harvested would be insignificant. Almost 88% of the piñon-juniper and juniper woodlands in Arizona are in the high-site category (Conner et al. 1990). High-site lands have the best potential for integrated resource management.

Silvicultural Approaches

Silviculture provides the tools for manipulating the woodland tree cover to sustain production of wood products and maintain woodland health. One chief goal of silviculture is to obtain satisfactory tree regeneration for the future. Silviculture can also be used to improve forage production and wildlife habitat and to create an aesthetically pleasant landscape. The Rocky Mountain Station is currently evaluating the effects of several overstory and slash disposal treatments on overstory growth and development, tree regeneration, forage quality and quantity, small mammal populations, nutrient cycling, and site productivity. This work is being conducted near Heber, Arizona, in cooperation with the Apache-Sitgreaves National Forests.

Managers from the USDA Forest Service, USDI Bureau of Indian Affairs, and other federal and state agencies also are attempting to develop prescriptions that would provide integrated resource management. Management prescriptions and objectives vary throughout the Southwest. Bassett (1987) reviewed the common silvicultural prescriptions and concluded that single-tree selection and two-step shelterwood methods are best for sustained stand health and productivity of woodlands. These methods are compatible with the dispersal patterns of

heavy tree seed, provide protected micro-sites for regeneration, and are aesthetically acceptable. There are, however, some disadvantages, especially related to the costs associated with intensive management and potential damage to residual trees during subsequent harvests. Bassett (1987) presented a detailed discussion of the trade-offs that must be evaluated in preparing a prescription. A single-tree selection treatment designed to reduce stand density but still retain uneven-aged structure as well as horizontal and vertical diversity is being studied at Heber. The USDI Bureau of Indian Affairs in Albuquerque, New Mexico is currently evaluating growth and yield on stocking level plots that contain different residual basal areas. These plots in western New Mexico and southern Colorado were harvested according to single-tree selection prescriptions. The effects of different stand densities on piñon nut production is being studied jointly by the Rocky Mountain Station and the Albuquerque Office of the Bureau of Indian Affairs. Nut production is important for tree regeneration, wildlife food, for the commercial piñon nut industry, and gathering by individuals. Group selection, which creates small openings within the stand, is less common and needs further study. Success from the forestry perspective would depend on achieving satisfactory regeneration from residual seedlings and seed, and from movement of seed into openings from the surrounding stand. Two-step and three-step shelterwood methods are being evaluated in New Mexico. A modified one-step or simulated shelterwood can be used when advance regeneration is satisfactory.

The clearcut method and the seed-tree method generally result in unsatisfactory regeneration success because of poor seed dispersal. Small clearcuts can be appropriate when dwarf mistletoe (*Arceuthobium divaricatum*) control is necessary. Silvicultural prescriptions should be compatible with habitat type characteristics. Proper management for sustained production of the tree resources also requires additional growth and yield information related to site characteristics (Gottfried 1992a).

Wildlife-Range Approaches

Current management is integrating livestock and wildlife with the tree product objectives. A careful assessment of wildlife and other needs must be made to ensure tradeoffs in resource allocation are acceptable. Clearing small dispersed areas of trees benefits elk and mule deer, and livestock (Short et al. 1977). Openings create a more diverse landscape that favor many wildlife species. For example, small mammal populations increase within cleared areas (Severson 1986), which would attract predatory birds and mammals. Birds that feed on insects associated with openings should also benefit from this landscape. However, openings should not be too large (Severson and Medina 1983) and the woodlands should not become too fragmented. In many cases, the actual size of the openings may not be critical if continuous corridors of adequate width are maintained. Stands surrounding openings can remain untreated or be partially harvested. Forage production also is stimulated in areas harvested using an overstory removal cut and in group selection openings.

Managers must decide if cleared wildlife-livestock areas should be maintained or if trees should be allowed to reoccupy the sites. If trees are allowed to reoccupy the openings, a management scheme could be created that involves a variety of seral stands. There is a need to define spatial and temporal patterns by habitat type that maximize plant and animal diversity. Springfield (1976), Severson and Medina (1983), and Short and McCulloch (1977) present more in-depth reviews of range management and wildlife management within the woodlands.

Treatments that reduce tree densities, such as the single-tree selection and shelterwood, should benefit livestock and native ungulates by providing additional forage while maintaining some degree of thermal and hiding cover. However, the impacts of residual trees on understory dynamics is unclear. The relationships among cover, tree regeneration, and forage yields of the different understory species still need better definition. How much of a reduction in tree density is necessary to produce significant increases in the production of herbaceous species while not compromising the tree resources? Large reductions in tree canopy cover are necessary to improve total herbage yields (Arnold et al. 1964, Pieper 1990). However, while total herbage biomass and blue grama biomass decline with increased canopy cover, the biomass of cool-season grasses such as piñon-ricegrass (*Piptochaetium fimbriatum*) and New Mexico muhly (*Muhlenbergia pauciflora*) actually increase with increased tree cover (Pieper 1990). Further research relating herbage production to stand density is being planned.

Many high-site areas treated during piñon-juniper control programs have been reoccupied by healthy stands of trees, often the result of advance regeneration that survived the initial treatment. Managers must decide in these situations if the trees should be allowed to recover or if the area should be retreated to encourage herbaceous production. If regeneration is vigorous and dense enough to result in a healthy tree stand, the area should not be treated again because successful regeneration of large openings is difficult. The young stands would be part of the diverse landscape required by many wildlife species. Increased herbage production would occur until the tree canopy closes.

Slash Disposal

Slash disposal after harvesting or vegetation type conversion is another important issue in woodland management. Slash disposal may vary according to management objectives (Severson and Medina 1983). On any one management area, several slash treatments may be warranted and practical. For example, burning slash in large piles is unacceptable because of the adverse effects on soils and overall site productivity (Tiedemann 1987). However, slash in small piles may be burned with the intent of creating areas containing earlier seral stages

that increase floristic species richness on the treatment area. Other piles could be left unburned to provide habitat for small mammals (Severson 1986). Slash piles can break up sight distances and provide security cover for wild ungulates. Slash can be scattered in some areas to provide protection for herbaceous growth and to provide nursery sites for young trees. On other sites, scattered slash could be burned in a cool fire to promote temporary increases in nutrient contents of the herbaceous forage components. Burning should probably be delayed until the second growing season to allow for vegetation recovery.

Slash also provides some erosion protection by retarding surface water movement and by serving as a place where sediment can accumulate and not be lost from the site. A study of several slash disposal treatments showed that a slash-scattered treatment resulted in the least surface runoff and sediment loss and in relatively higher soil moistures (Wood and Javed 1992). This treatment also had the best vegetation response, which helps protect the soil, slows runoff and erosion, and increases infiltration. Slash burning and complete slash removal had the reverse effect. Slash can also be placed into small gullies to reduce erosion.

SINGLE RESOURCE EMPHASIS

While the wisdom of woodland control for production of forage for livestock on high-site public lands is questionable, some private owners may still prefer this option. Some benefits of multiresource management can still be achieved. Fuelwood and other wood products should be harvested. This harvest provides a cash return and makes subsequent activities easier and more economical. One approach, even when livestock production is the main objective, is to create mosaics of tree-covered areas interspersed with grass-forb-dominated areas. Such a pattern should favor a mixture of cool-season and warm-season grasses (Pieper 1990). A mosaic landscape is beneficial for wildlife and livestock and is aesthetically pleasing.

Another approach is to create savannahs by retaining some of the larger piñon and juniper trees from the original stand. Such savannahs can be more aesthetically pleasing than huge openings and still provide some limited wildlife habitat benefits as well as shade for livestock. Although large savannahs have drawbacks, this treatment should be integrated into a landscape that includes untreated and lightly treated stands as well as small openings.

Management of Low-Site Lands

Tree control to enhance forage production is easier to justify on low-site lands where management for tree products is not economically or biologically feasible. Herbage production should be stimulated by normal range management activities, with the actual techniques depending on equipment demands and site characteristics. Stands of low stature and density could be the result of arid conditions that would affect the quantity, quality, and rate of replacement of grasses and forbs. Site factors have to govern the selection of forage species.

Even when tree control is desired, managers should consider the size and placement of openings. Large openings are detrimental to deer and elk and to many nongame species. Mosaics of trees interspersed with cleared areas create a more acceptable landscape. The covered areas provide hiding and thermal cover for both wildlife and livestock. It is common to find cattle concentrating in pockets of residual trees within chained or cabled areas.

Regardless of the treatment and objectives on high- and low-site lands, proper grazing management is an important key to successful range improvement activities. Although data are scarce, there is a general belief that the poor response of native and introduced forage species to tree control activities was related to poor livestock management. Animals were often allowed onto areas before the plants had become established. Some grazing deferral for at least two grazing seasons probably is necessary although the amount must be governed by site, climate, and forage species.

CONCLUSION

Piñon-juniper woodlands cover large areas of the Southwest. The woodland ecosystem is not homogeneous but consists of a large number of habitat types. Management of these lands is controversial, but has evolved over the years to the current recognition of their value for many natural resources. High-site woodlands provide the best opportunities for multiresource management including tree products, wildlife habitat, herbaceous production for wildlife and livestock, watershed protection, and recreation. Tree control may be easier to justify on low-site lands, but other resource values still must be considered. There are many gaps in our ecological knowledge of the piñon-juniper woodlands, and the full range of management options, linked to a recognition of habitat type differences, still needs to be evaluated. Management and research personnel should work together to ensure the sustained health and productivity of this important ecosystem.

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Woody Debris in Undisturbed Piñon-Juniper Woodlands of New Mexico

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Abstract — In piñon-juniper woodlands, standing dead and down woody materials play significant ecological roles both physically and with respect to nutrient relationships. These semiarid ecosystems have slow decomposition rates and woody debris may remain intact for extended periods of time. The presence of debris over long periods inhibits soil erosion directly by covering the surface and preventing sheet erosion and by creating debris dams that slow runoff. The purpose of this study was to describe the structure of two undisturbed, uneven-aged mature piñon-juniper stands in New Mexico and to quantify the volume of standing dead and down piñon and juniper wood in areas isolated from human disturbance. These data provide a baseline with which to determine more precisely the contribution of dead woody debris to the piñon-juniper ecosystem and the impact of woody debris removal.

INTRODUCTION

In piñon-juniper woodlands, standing dead and down woody materials may play significant ecological roles both physically and with respect to nutrient relationships. These semiarid ecosystems have slow decomposition rates and woody debris may remain intact for extended periods of time. The presence of debris over long periods inhibits soil erosion directly by covering the surface and preventing sheet erosion and by creating debris dams that slow runoff. These micro-catchments may also provide microsites for germination and establishment of grasses and forbs. Standing dead snags provide shelter for cavity nesting birds. Standing dead and associated below-ground dead rooting systems also decay slowly. Thus, standing dead wood can act as a soil binder, slowing soil loss from disturbance. Despite slow decomposition rates, downed woody materials are important storage and recycling points for nutrients in these systems. This material is also important to ensure the colonization of ectomycorrhizal fungi by tree roots.

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Piñon-juniper woodlands are and historically have been subject to extensive resource use, particularly for fuelwoods. Much of the standing dead debris and intact down debris is removed by fuelwood harvesters. Thus, in effect, an important component of the piñon-juniper ecosystem may be removed, leading to long-term degradation of the resource.

Piñon-juniper woodlands cover an extensive portion of the southwestern United States. Estimates range from 43 to 100 million acres (17-40 million ha) (Tueller et al. 1979). Dick-Peddie (1993) estimates 10.4 million (4.1 million ha) of coniferous and mixed woodlands in New Mexico alone with an additional 7.7 million acres (3.1 million ha) of the Juniper savanna ecotone. Despite their abundance, undisturbed uneven-aged mature piñon-juniper woodlands are extremely rare due to heavy use by both people and domestic animals. The long history of intensive human use of piñon-juniper woodlands has made undisturbed woodlands "one of the most significant and difficult ecosystems to represent" (USDA Forest Service 1983).

One of the first steps in understanding the importance of woody debris to the piñon-juniper system is to quantify woody debris in undisturbed, uneven-aged mature piñon-juniper woodlands. The purpose of this study was to describe the structure of these piñon-juniper stands in New Mexico and to quantify the volume of standing dead and down piñon and juniper wood in areas isolated from human disturbance. These data should provide a baseline with which to determine more

precisely the contribution of dead woody debris to the piñon-juniper ecosystem and the impact of woody debris removal.

STUDY AREAS

Two piñon-juniper areas were chosen for study. Both are designated as candidate Research Natural Areas (RNAs). Because of their relative isolation from human disturbance, these areas represent good examples of uneven-aged mature piñon-juniper woodland.

Comanche Canyon

The proposed Comanche Canyon RNA, in the Carson National Forest of northern New Mexico, was identified as an outstanding example of piñon-juniper woodland and was recommended for designation as an RNA (USDA Forest Service 1989). The extreme remoteness of Comanche Canyon has protected it from both fuelwood collecting and post cutting. The site is inaccessible to domestic livestock, and the last large fire in this area occurred more than 100 years ago (USDA Forest Service 1986).

The Comanche Canyon area is located approximately 10 miles (16 km) directly west of El Rito, Rio Arriba County, New Mexico. The center is located at latitude 36° 21' N., longitude 106° 21' W. Elevation ranges from 7200 feet (2182 m) to 7737 feet (2344 m). Annual precipitation at Abiquiu Dam, approximately 8 miles (12.8 km) southwest of the site, is highly variable, ranging from 12.7 to 21.9 inches (32.3 to 55.6 cm), and is divided between summer rains and winter snows. Frost-free days average about 160-180 per year, and annual insolation is 80% (Tuan et al. 1973). Average temperature ranges from 28 to 72° F (-2 to 22.2° C), with a low of -25° F (-31.6° C) and a high of 95° F (35° C).

The area covers approximately 450 acres (180 hectares) of piñon-juniper forest. A distinctive mesa slopes down to a gentle grade on the north side of the area, where thick piñon-juniper forest is periodically interspersed with large flats of big sage (*Artemisia tridentata* Nutt.). The south side of the ridge drops off fairly steeply to a series of sandstone cliffs that lead down to an intermittent stream in the canyon bottom.

Piñon pine (*Pinus edulis* Engelm.) is the dominant tree throughout the area of Comanche Canyon, with the exception of a few open stands of sagebrush and some small grassland meadows. Utah juniper (*Juniperus osteosperma* [Torr.] Little) is often co-dominant; one-seed juniper (*Juniperus monosperma* [Engelm.] Sarg.) and Rocky Mountain juniper (*Juniperus scopulorum* [Sarg.]) are present as well, but are less common. The piñon-juniper vegetation type covers approximately 360 acres (144 ha), Great Basin sagebrush cover 76 acres (31 ha), and grama-galleta steppe covers 14 acres (5 ha). Most of the piñon-juniper woodland at Comanche Canyon is closely associated with the *Pinus edulis* Engelm./*Bouteloua gracilis* (H. B. K.) Steud. habitat type of Dick-Peddie (1993).

Hymenoxys richardsonii (Hook.) Cockll. (pinque), *Bahia dissecta* (Greg) Britt., and *Erysimum capitatum* (Dougl.) Greene are some of the principal forb species; *Boutelous gracilis* (H. B. K.) Steud. (blue grama) is the most common of the many grasses. *Yucca baccata* Torr. and various species of cacti (*Opuntia, Echinocereus, Coryphanthus,* and *Mammilaria* spp.) are also found here. Mountain mahogany (*Cerococarpus montanus* Raf.) becomes co-dominant with piñon in the southwestern portion of the area. Big sage is a common shrub occurring in both piñon-sage woodland and in nearly pure stands of sagebrush, especially in the southwestern portion of the area.

Soils at the site, formed from sandstone and shale, are classified as Eutroboralfs. They are mesic, sandy-mixed, or sandy loam residuum (Hunt 1978) and are highly variable. The soil on the mesa top is very fine and is covered with a layer of small stones. The soils on the slopes and knolls are also fine, but these areas are very cobbly. Soils in the piñon-juniper woodland and in the sagebrush areas are very fine and have a moderate organic material content (site description in more detail in Merola 1992).

Largo Mesa

The proposed Largo Mesa RNA is located in the Apache National Forest of west-central New Mexico, approximately 13 mi (21 km) SW of Quemado, Catron County, longitude 108° 35' W, latitude 34° 10' N. The elevation ranges from 7760 ft (2360 m) to 8025 ft (2450 m) on the mesa top. The average annual rainfall is 16 in (41 cm); most falls from May to October. Average annual snowfall in this region is 31 in (79 cm). The mean annual temperature is 48° F (8.9° C); approximately 150 days per year are frost-free.

The area encompasses approximately 300 acres (121 ha) of piñon-juniper woodland. The vegetation is piñon-juniper woodland surrounded by blue grama grassland. One-seed is the only juniper species on the site. A grass layer is nearly continuous in the woodland. Shrub and forb cover is low. Mountain mahogany, rabbitbrush (*Chrysothamnus nauseosus* [Pall.] Britt.), and snakeweed (*Gutierrezia sarothrae* [Pursh.] Britt. and Rusby) are the most common shrubs. This piñon-juniper woodland is more open than on the mesa top at Comanche Creek.

Largo Mesa derives from a Tertiary volcanic ash flow. The mesa top is flat, with steep scarps descending from all sides. Soils are Ustochrepts of generally fine, sandy loam, or loam textures.

Largo Mesa is somewhat less isolated than Comanche Canyon from human disturbance. There is no developed water source and cattle rarely graze on the site, but past woodcutting may have occurred. More complete descriptions of the site are presented in USDA Forest Service (1992).

METHODS

Three sites were chosen for study at Comanche Canyon: mesa top, mesa slope, and sage-piñon woodland. The flat mesa top is characterized by a relatively pure piñon-juniper woodland. The steep northern slope is rocky; Gambel's oak (*Quercus gambelii* [Nutt.]) occurs in scattered patches. The sagebrush site runs along the toe-slope of the mesa, where piñon-juniper woodland is interrupted by patches of big sagebrush. Only the flat mesa top was studied at Largo Mesa.

Two types of surveying methods were used in this study. First, woody debris (defined here as dead tree trunks and branches lying on the ground) was quantified along line transects. Second, standing trees (live and dead) and canopy characteristics were quantified within circular plots. All measurements include only piñon and juniper. One-seed juniper and Utah juniper, similar in habit and ecology, were lumped together for all measurements.

Methods for quantifying woody debris follow "Guidelines for Conducting Logged Area Analysis" (LAA) (USDA Forest Service 1979). Fifteen 100-ft (328-m) transects were randomly oriented within each of the three sites at Comanche Canyon and on the top of Largo Mesa. Along each transect line, the diameter of each piece of piñon and juniper debris that crossed the line was recorded. Diameter, perpendicular to the length of the debris, was measured at the point of intersection of the transect line with the central axis of the debris. Only debris $\geq$ 2.0 in (5 cm) diameter and $\geq$ 2.0 ft (0.6 m) long was included. On every fourth transect line, debris length and diameters at the small and large ends were also measured. Piñon and juniper debris were difficult to differentiate and are combined for most analyses.

Debris volumes were calculated on a personal computer using the LAA program. This program calculates cubic foot volume/acre, V, as $[\pi^2 (\Sigma D^2)/8L] * [43560/144]$, where D = debris diameter (inches), L = debris length (feet). Tons/acre (W) are calculated as $W = 11.6437\ S\ (\Sigma D^2)/L$, where S=specific gravity (60% moisture content is assumed). Specific gravity of piñon is 0.38, and of juniper is 0.36 (USDA Forest Service 1979).

Standing dead and live mature trees, canopy characteristics, and regeneration (young trees) were quantified in 0.05-acre (0.02-ha) circular plots with a radius of 26.3 ft. (8.03 m). These overstory measurements approximately follow the methods of Gottfried (1989). One plot was established at the midpoint of every third transect line, for a total of five plots in each site. On each plot, the following were recorded: tree species, whether alive or dead, diameter at root collar (DRC) of all stems, number of stems, height, maximum canopy diameter, and canopy diameter perpendicular to the maximum diameter. Mature trees were defined as those with DRC $\geq$ 2.0 in (5 cm). Numbers of seedlings (DRC < 2.0 in [5 cm], height < 4.5 ft [1.3 m]) and saplings (DRC < 2.0 in [5 cm] and height $\geq$ 4.5 ft [1.3 m]) of piñon and juniper were recorded.

Density (number of stems/plot) and live and dead tree basal area were calculated for each species. Basal area is the sum of the cross-sectional areas (at the root collar) of all mature trees on the plot. For trees with stems divided at the root crown, the equivalent diameter at root collar (EDRC) was calculated as $\sqrt{\Sigma(DRC_i)^2}$ (Chojnacky 1985).

Cubic-foot volume/acre of standing trees was calculated based on equations for trees in the Colorado Plateau States (Colorado, eastern Utah, Wyoming). The following equations were used (from Chojnacky 1985):

Piñon:

$$V = (-0.20296 + 0.150283[DRC^2 \times HT]^{1/3} + 0.054178\ [STEM])^3,$$

Rocky Mountain juniper:

$$V = (0.02434 + 0.119106[DRC^2 \times HT]^{1/3)})^3,$$

Utah juniper:

$$V = (-0.08728 + 0.135420[DRC^2 \times HT]^{1/3} - 0.019587\ [STEM])^3,$$

where: V = gross volume (cubic feet) of tree, including bark,
DRC = diameter or equivalent diameter at root collar (in),
HT = tree height (ft),
STEM = 1 if single-stemmed, 0 if multiple-stemmed.

The equation for Utah juniper was used for the mixture of Utah and one-seed junipers. Chojnacky (1985) based his equations on measurements of all branches 1.5 inches (3.8 cm) or greater in diameter. In this study, a minimum branch diameter was 2.0 in (5 cm) was used. Adjustments can be made for these differences, but the overall trends are unlikely to change significantly. Another potential source of error is introduced when Chojnacky's equations, which were derived from data collected in a wide geographic area, are applied to a local area (Chojnacky 1985). However, specific equations for the Comanche Canyon and Largo Mesa sites are not available, and the general equations should provide a reasonable estimate of volumes.

Data were logarithmic transformed to improve the normality and stabilize variances across groups. Analysis of variance (ANOVA) was carried out on measurements of debris volume, stand density and volume, seedlings, saplings (as the dependent variables) and site (Comanche Canyon, Largo Mesa), species (piñon, juniper), and status (living or dead) as the independent variables. The sites within Comanche Canyon and between the Comanche Canyon mesa top and the Largo Mesa mesa top were compared. All measurements were calculated in English units and converted as needed to metric. Conversion values are listed in the tables. Transects or plots were used as the basic sampling unit for these analyses.

RESULTS

Stand Characteristics

The total volume of mature, standing trees of both genera, live and dead, ranged from 1137.2 cubic feet/acre (79.6 m^3/ha) on the mesa slope to 1631.6 cubic feet/acre (114.2 m^3/ha) on the mesa top at Comanche Canyon (table 1). The overall ANOVA for total volume was significant (p = 0.01). The

differences among sites were not significant, but both tree status (alive or dead) ($p = 0.01$) and species ($p = 0.01$) were significant. Standing dead trees contributed significantly less to total volume than did living trees. The volume of piñon was greater than that of juniper at Comanche Canyon, but less at Largo Mesa (table 1).

Densities (number of stems/acre) of standing piñon and juniper varied from 384 (949 stems/ha) at Largo Mesa to 876 (2165/ha) on the mesa slope at Comanche Canyon (table 1). Densities were significantly different among sites ($p = 0.05$), between live and dead trees ($p = 0.01$), and between species ($p = 0.01$). Density of living trees was greater than that of dead trees, as expected for a healthy stand. The density of piñon was greater than that of juniper at Comanche Canyon, but less at Largo Mesa (table 1). Of the contrasts in densities among sites, the mesa slope and sage sites at Comanche Canyon were significantly different ($p = 0.05$). The mesa top and mesa slope at Comanche Canyon were not significantly different. The mesa top and sage sites at Comanche Canyon were not significantly different, nor were the mesa tops at Comanche Canyon and Largo Mesa.

Tree size also varied among sites. Piñons and junipers were largest (in diameter) and tallest on the mesa tops at both sites and smallest and shortest on the mesa slope at Comanche Canyon (table 2). The mean DRC of piñon (all standing, mature trees) varied from 5.4 in (13.5 cm) on the mesa slope to 8.2 in (20 cm) on the mesa top at Comanche Canyon. Mean height varied from 12 to 16 ft (3.8 to 4.9 m). The mean DRC of juniper ranged from 6.8 in (17 cm) on the mesa slope at Comanche Canyon to 14.4 in (36 cm) at Largo Mesa. Mean height was between 10 and 14 ft (3.1 to 4.2 m) (table 2). Distribution of basal area by tree diameter classes is shown in figure 1 for piñon and in figure 2 for juniper.

Regeneration was occurring on all sites (table 3). Both site ($p = 0.01$) and species ($p = 0.01$) were significant for number of seedlings. Only species ($p = 0.01$) was a significant factor for number of saplings. More piñon than juniper seedlings and saplings were growing in all surveyed areas. The mesa slope had significantly more seedlings (mean 1228/acre [3042/ha]) than did the mesa top (mean 500/acre [1239/ha]) ($p=0.01$) or sage (mean 672/acre [1664/ha]) ($p = 0.05$) sites. Sapling densities ranged from 8 to 56/acre (20 to 139/ha) (table 3).

Table 1. — Densities (# stems/A), basal area (sq ft/A), volume (cu ft/A), and (standard deviation) of standing trees (live and dead) at Comanche Canyon and Largo Mesa.

Measure	Species	Status	Site			
			Comanche Canyon			Large Mesa
			Mesa Top	Mesa Slope	Sage	Mesa Top
Density	Piñon	Alive	344[1] (76.3)	560 (201.9)	416 (147.2)	104 (40)
		Dead	24 (23.3)	92 (72.3)	24 (23.3)	24 (19.6)
	Juniper	Alive	208 (172.1)	208 (111.6)	52 (67.6)	252 (155.2)
		Dead	0 (0)	16 (18.1)	4 (8)	4 (8)
Basal Area	Piñon	Alive	133.8[2] (40.8)	101.1 (35.7)	116.1 (47.5)	43.5 (17.6)
		Dead	6.5 (6.7)	27.0 (18.4)	27.3 (31.5)	9.9 (12.1)
	Juniper	Alive	61.3 (60.2)	35.7 (28.4)	11.0 (15.6)	120.4 (79.6)
		Dead	0 (0)	5.0 (11.4)	0.1 (0.3)	9.5 (19)
Volume	Piñon	Alive	1262.4[3] (494.9)	739.2 (387.8)	967.2 (575.6)	420.8 (256.9)
		Dead	27.2 (33.6)	165.2 (117.2)	65.5 (117.6)	53.6 (87.7)
	Juniper	Alive	342.0 (356.6)	189.6 (149.3)	152.6 (206.2)	710.8 (563.1)
		Dead	0 (0)	43.2 (74.9)	0.1 (0.27)	53.2 (118.9)
Volume Total			1631.6	1137.2	1205.5	1238.4

[1]To convert to stems/ha, multiply by 2.471.
[2]To convert to m^2/ha, multiply by 0.2296.
[3]To convert to m^3/ha, multiply by 0.06997.

Table 2. — Average diameter in inches and (standard deviation) at root collar (DRC) and height in feet of pinyon-juniper at two sites.

Species	Average Tree Size	Site: Comanche Canyon Mesa Top	Comanche Canyon Mesa Slope	Comanche Canyon Sage	Large Mesa Mesa Top
Piñon	DRC	8.21[1] (3.5)	5.4 (3.0)	6.7 (3.4)	8.1 (3.4)
	HT	16.02[2] (5.3)	12.0 (5.3)	14.0 (5.1)	16.0 (5.8)
Juniper	DRC	12.8 (5.1)	6.8 (3.8)	11.5 (7.9)	14.4 (5.8)
	HT	14.0 (2.5)	10.0 (4.2)	13.0 (3.6)	13.0 (3.3)

[1] To convert to cm, multiply by 2.54.
[2] To convert to m, multiply by 0.305.

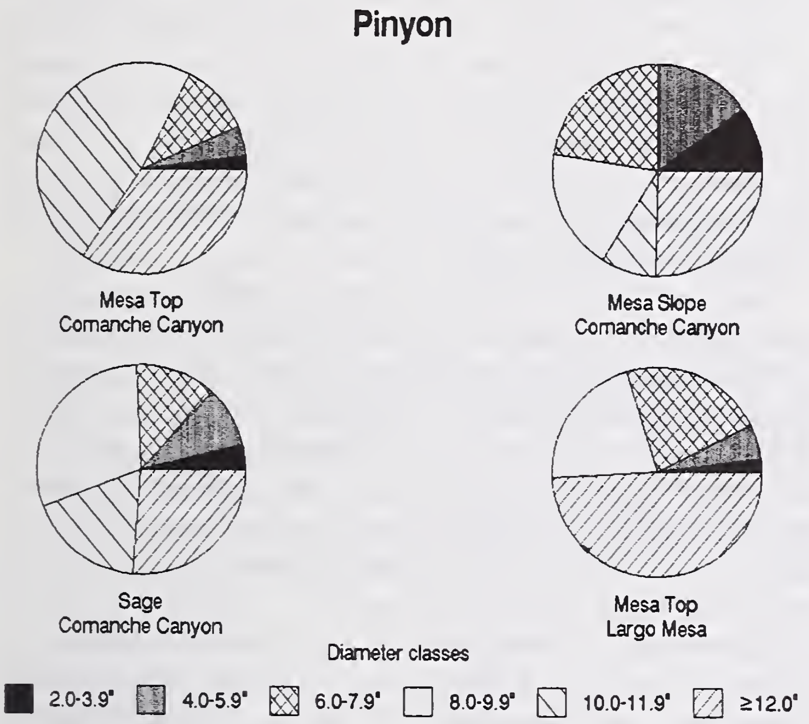

Figure 1. — Distribution (%) of basal area by diameter classes and sites.

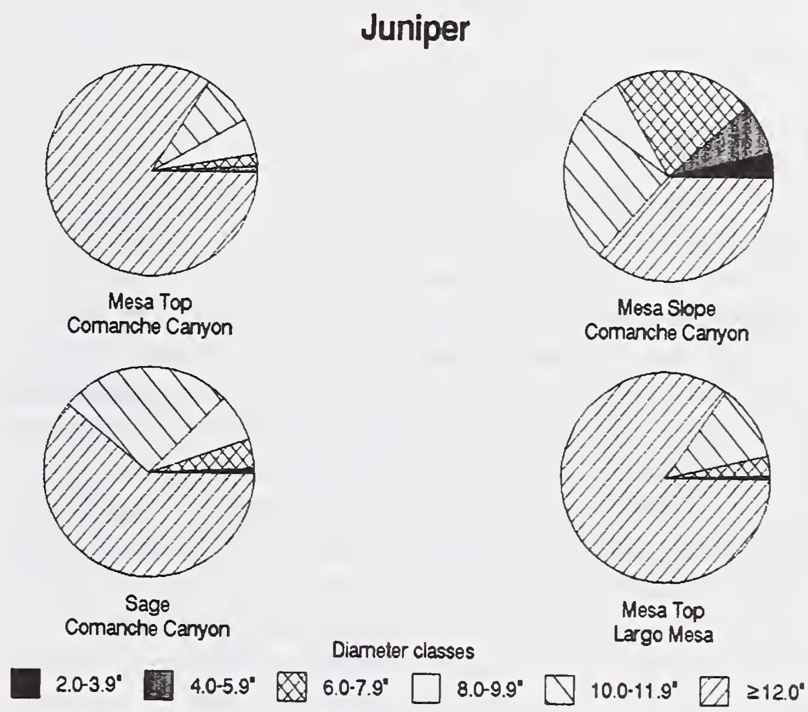

Figure 2. — Distribution (%) of basal area by diameter classes and sites.

Table 3. — Regeneration in # of trees/A and (standard deviation) of piñon and juniper at two sites.

Size Class		Site: Comanche Canyon Mesa Top	Comanche Canyon Mesa Slope	Comanche Canyon Sage	Large Mesa Mesa Top
Seedlings [<4.5 ft HT <2.0 in DRC]	Piñon	485[1] (258)	1180 (512)	636 (183.4)	428 (216)
	Juniper	16 (14.8)	48 (30.4)	36 (36.6)	160 (23.2)
Saplings [≥ 4.5 ft HT <2.0 in DRC]	Piñon	24 (38.6)	52 (45.6)	32 (27)	8 (9.6)
	Juniper	0 (0)	5 (13.2)	16 (24)	0 (0)

[1] To convert to trees/ha, multiply by 2.477.

Table 4. — Mean volume in feet^3/A, (standard deviation), weight in tons/A of dead and down piñon and juniper at Comanche Canyon and Largo Mesa.

Debris Quantity	Species	Site: Comanche Canyon, Mesa Top	Comanche Canyon, Mesa Slope	Comanche Canyon, Sage	Large Mesa, Mesa Top
Volume	Piñon and Juniper	422.2[1] (250.3)	469.5 (346.9)	66.2 (117.3)	231.8 (303.5)
Weight	Piñon and Juniper	8.0[2] (4.7)	8.7 (6.4)	1.2 (2.2)	4.3 (4.5)

[1]To convert to m^3/ha, multiply by .06997.
[2]To convert to Mg/ha, multiply by 2.24.

Volumes and Weights

The volumes and weights of woody debris were variable among transect lines within and among sites (table 4). The mean volume of woody debris (segments ≥ 2.0 ft [0.6 m] long and ≥ 2.0 in [5 cm] diam.) of piñon and juniper combined ranged from 66.2 (± 117.3 S. D.) cubic feet/acre (4.6 m^3/ha) in the sage site to 469.5 (± 346.9 S. D.) cubic feet/acre (32.8 m^3/ha) on the mesa slope at Comanche Canyon. The amount of debris was intermediate at Largo Mesa, with a mean of 231.8 (± 303.5 S. D.) cubic feet/acre (16.2 m^3/ha). Site was a significant factor in the analysis of debris volume ($p = .01$). Volumes differed significantly between the mesa top and sage sites and between the mesa slope and sage sites at Comanche Canyon, and between the mesa tops of Comanche Canyon and Largo Mesa ($p = .01$). All woody debris at Comanche Canyon was piñon pine; juniper contributed a small amount of woody debris at Largo Mesa. Weight of debris followed the patterns of volume (table 4).

To better understand these values, stand volume ratios of live standing to dead standing, live standing to dead down, and dead down to dead standing have been calculated (table 5). Of these, the values of live standing to dead down is the more significant ratio. In this study the sage site had less dead down material in relation to live standing volume. Both mesa tops had similar ratios where for every 100 cubic feet per acre (7 m^3/ha) of stand volume you could expect 20 to 25 cubic feet per acre (1.4 - 1.8 m^3/ha) of down material.

Table 5. — Ratio of live standing (LS) to dead standing (DS) and dead down (DD) volume of pinyon and juniper at two sites.

Site		Ratio: LS/DS	LS/DD	DD/DS
Comanche Canyon	Mesa Top	59:1	4:1	16:1
	Mesa slope	4:1	2:1	2:1
	Sage	17:1	17:1	1:1
Largo Mesa	Mesa Top	11:1	5:1	2:1

DISCUSSION

Debris and overstory measurements showed considerable variability at all levels: among transect lines or plots, among sites at Comanche Canyon, and between the two locations. Piñon-juniper woodland is not a uniform habitat (Aro 1971, cited in Ronco 1987). Variation in slope, aspect (Pieper and Lymbery 1987), elevation, soils, and other physical features contribute to variation in the biotic features.

Variability in the measurements was especially high on the mesa slope at Comanche Canyon. All transect lines and plots were located on the northwest slope, so aspect is not the source of the variability. Understory vegetation did vary noticeably among survey units. The cover of Gambel's oak ranged from 0 to 30%. This could have increased the variability in debris quantity and density of mature trees along the slope. A similar patchiness was observed in the percent cover of big sagebrush in the sage site at Comanche Canyon.

Despite high variability, some general trends were seen. Several measures of debris quantity, overstory characteristics, and regeneration differed significantly among sites at Comanche Canyon. The mesa top and mesa slope seemed to have much higher volumes of woody debris than did the sage site at Comanche Canyon. All of the woody debris at Comanche Canyon and most of it at Largo Mesa was piñon, despite the conspicuous presence of junipers at both locations. Volume of standing trees in the overstory did not differ significantly among sites, but the density of trees was highest on the mesa slope at Comanche Canyon. Regeneration was also greatest on the mesa slope.

The density of live piñons on the mesa slope at Comanche Canyon was 560/acre (1384/ha). This compares very closely with the density of 555/acre (1371/ha)on a northwestern slope of 11-20% in central New Mexico (Pieper and Lymbery 1987).

Regeneration may be higher in sites without debris removal. Survival of one-seed juniper seedlings planted near Grants, New Mexico, was higher when mulched with wood chips than when no mulch was applied (Fisher et al. 1987). A similar enhancement of seedling survival may occur in undisturbed piñon-juniper woodlands, where woody debris breaks down and acts as a mulch.

This study has shown the importance and extent of dead and down material in these particular types of piñon-juniper stands. For mesa tops and slopes in these stands, it would be reasonable to manage so that for every 15 or 20 cubic feet per acre (1.1 - 1.4 m^3/ha) of live tree volume there would be 4 - 5 cubic feet per acre (.3 - .4 m^3/ha) of dead and down material. Leaving material in place and adding material through slash disposal after cutting are important management components that could be used in this ecosystem.

Other sites (e.g., south slope, grass-woodland transition, mountain mahogany-piñon) exist in the piñon-juniper woodland at Comanche Canyon. In addition, 11 other piñon, one-seed juniper habitat types are present in New Mexico (Dick-Peddie 1993). Surveying these habitats for debris and overstory traits would help better define the structure of piñon-juniper woodlands. This study provides an undisturbed benchmark for a broader study.

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Insect and Disease Associates of the Piñon-Juniper Woodlands

Terrence J. Rogers[1]

In order to successfully manage piñon-juniper ecosystems for sustainability and social needs we must also look at and understand the role of insects and diseases associated with this ecosystem. At the present time, however, little is known about the role of insects and diseases in the piñon-juniper ecosystem. This is not really surprising since until just recently, last ten years or so, the piñon-juniper type was managed primarily for forage production with some considerations also being made for fuelwood and piñon nut production. With the advent of the Forest Health Initiative and the Piñon-Juniper Initiative, however, a more indepth understanding of the role insects and diseases play in the piñon-juniper woodlands and their potential impacts on management objectives is necessary if we are to manage this system for sustainability and desired social needs.

Insect activity in the piñon-juniper forest cover type appears to be correlated with extended periods of drought which predisposes large areas of host type to attack. During periods of average rainfall, insect activity in the piñon-juniper type is usually undetectable. Drought acts as a "trigger" triggering ecological processes which eventually leads to insect outbreaks that often extend over thousands of acres of susceptible host type.

Probably the most important group of insects associated with the piñon-juniper ecosystem are the *Ips* bark beetles belonging to the family Scolytidae. During extended periods of drought *Ips* bark beetles *(Ips confusus)* often increase to outbreak levels causing widespread tree mortality on thousands of acres of host type. Mortality is often patchy consisting of small groups of five to ten fading trees. In some cases, entire viewsheds and landscapes may be affected. Other Scolytid bark beetles affecting piñon are the twig beetles. Twig beetles, *Pityophthorus spp.* and *Pityogenes spp.*, are frequent pests of piñon pines. Normally they attack shaded-out and storm-damages twigs and branches. Occasionally, however, twig beetle populations locally build-up in drought-stressed injured trees. When at out break levels, entire viewsheds and landscapes can be affected.

Outbreaks of the piñon needle miner, *Coleotechnites edulicola*, and the piñon pine needle scale, *Matsucoccus acalyptus*, also occur during periods of below average precipitation levels and can cause widespread defoliation damages to viewsheds and landscapes. Several years of heavy defoliation damages can predispose infested trees to *Ips* bark beetle attack and subsequent mortality.

Other incidental insects found associated with piñon include the tiger moth, *Halisidota ingens*, the piñon sawfly, *Zadiprion spp.*, piñon spindle gall midge, *Piñonia edulicola*, bark moths, *Dioryctria spp.*, and *Vespamima spp.*, and the piñon pitch nodule moth, *Petrova arizonensis.*

Insects of note associated with junipers include the western cedar borer, *Trachykele blondeli*, and the juniper twig pruner, *Styloxus bicolor*. The western cedar borer is an aggressive pest of junipers and Arizona cyprus in New Mexico. It belongs to the buprestid beetle group also known as metallic or flatheaded wood borers. Unlike most other buprestids, the western cedar borer will attack and seriously injure or kill seemingly healthy trees. Considerable damage is found in some juniper stands; older, larger trees appear to be favored by these beetles. The juniper twig beetle, also found attacking junipers and Arizona cyprus causes twig dieback. This beetle belongs to the cerambycid beetle group also known as roundheaded wood borers.

Unlike insect outbreaks which are generally cyclical and at times cause seemingly spectacular damages and mortality across viewsheds and landscapes, diseases are more insidious. That is once a tree is infected with a disease pathogen, it may take years before the symptoms appear and several more years before the disease infected tree dies. Mortality resulting from disease infections is usually highest in young, immature trees.

Some diseases occurring in the piñon-juniper woodlands include the mistletoes and root rots. Mistletoes, *Arceuthobium divaricatum* on piñon and *Phoradendron juniperinun* on juniper, are parasitic plants that injure and eventually kill their woody hosts by stealing water and essential nutrients. Mistletoe plants vary in color from yellow to green to red-green. Piñon pine dwarf mistletoe plants consist of small conspicuous male and female shoots approximately two to three inches in length protruding through the bark of the infected branches. True mistletoe plants very in length from a few inches to several feet. Symptoms of infection include swelling at infection sites, branch

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dieback, and formation of witches' brooms. Dwarf mistletoes spread by shooting seeds from explosive berries. True mistletoes are spread by birds that eat the mistletoe berries. Seeds pass through the birds unharmed and are spread in their feces.

Root disease infected trees are difficult to diagnose since symptoms above ground can resemble symptoms caused by other insect and disease agents. Futhermore, little is known about their affects within the piñon-juniper ecosystem. Only recently have we observed and documented amalleria root rot killing piñon pines in northern New Mexico. Armillaria root rot occurs in expanding pockets, often with mortality at the center. The entire crowns of infected piñon saplings usually turns reddish-brown all at once. Dieback, thinning foliage, or yellowing of the crown is characteristic of older, infected piñon trees. This disease spreads by means of spores and rhizomorphs. When the fungus contacts the tree's root or root collar, it penetrates the bark and enters the living tissue. Cellulose is consumed leaving the root light-colored and causing the tree's butt to rot.

In summary, there many insects and diseases associated with the piñon-juniper woodlands. Their presence does not mean they are a forest pest. As we intensify our management activities within the piñon-juniper woodlands, we will have to monitor the impacts of resident insects and diseases to determine (1) What kinds of damages are occurring, (2) whether or not they are significant, and (3) their impacts on management objectives.

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Rehabilitation of Southwestern Rangelands Using Sewage Sludge: Technology Applicable to Piñon-Juniper Ecosystems?

Richard Aguilar[1]

Abstract — Forest Service researchers have been conducting studies on land application of sewage sludge to degraded rangeland for nearly a decade. The basic premise is that soils in degraded sites, which often have had a history of heavy livestock grazing, are depleted in organic matter. Subsequently, any attempt at improving the site potential and attaining a sustainable, higher level of productivity in these areas must consider restoring soil organic matter and associated nutrients to pre-livestock grazing levels. Rehabilitation of degraded lands can employ a passive approach (e.g., removal of grazing pressure) or an active approach (immediate improvement of the existing condition of the soil or vegetation, such as fertilization). A sludge amendment application study (1985-1989) investigated the effects of different quantities of municipal sewage sludge on vegetative growth and plant and soil chemistry. Results from this study showed that a one-time surface application of sewage sludge at 22.5 to 45 Mg ha^{-1} (10-20 tons acre^{-1}) significantly increased plant production and ground cover without producing undesirable levels of potentially hazardous sludge-borne constituents, including heavy metals, in either soils or plant tissues. Current studies are investigating the effects of sludge on rangeland hydrology and determining the feasibility of large-scale sludge application projects on public rangelands. Increased plant canopy and ground cover resulting from sludge amendments have significantly increased infiltration and reduced surface runoff. Many areas within piñon-juniper woodlands are characterized by soils depleted in organic matter and would probably respond favorably to an organic amendment in the form of municipal sewage sludge.

INTRODUCTION

The productivity of piñon-juniper ecosystems is highly dependent upon edaphic properties such as soil depth, soil organic matter content, soil fertility, soil water-holding capacity. Accelerated erosion, a problem long recognized on agricultural lands, is similarly becoming recognized as a significant problem on both rangeland and piñon-juniper ecosystems. Sauerwein (1984) estimated the total piñon-juniper habitat area in the western United States at over 32 million hectares and pointed out that erosion rates and downstream sediment problems on many of these lands are excessive. Because piñon-juniper stands often occur on shallow, stony, or rocky soils, the maintenance of surface litter and soil organic matter, and the preservation of soil profile depths are critical in sustaining productivity (Renard 1987).

Imprudent livestock grazing (overgrazing) has been the most formidable degrading force on arid and semiarid lands in the United States (Sheridan 1981). Many southwestern lands experienced heavy livestock grazing over the past century and this overgrazing lead to a substantial reduction in total plant cover and density (Dortignac and Hickey 1963). The cumulative effects of livestock pressure on rangeland resources has led to a significant decrease in annual forage production, decreased vegetative cover, increased soil compaction with a reduction in

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surface voids and infiltration (these factors, in turn, increase overland flow), and decreased soil organic matter content (Dregne 1977). Similar effects have been recorded on adjoining piñon-juniper woodlands (Springfield 1976).

The loss of vegetative cover through overgrazing, in particular, has greatly increased the erosion potential of soils in semiarid regions (Sheridan 1981). Any successful attempt at restoring grassland and understory production in these degraded areas will require increased plant production, reduction in soil erosion, and ultimately, replenishment of soil organic matter (El-Tayeb and Skujins 1989). Soil organic matter influences virtually all aspects of soil fertility and plays an important role in soil/water relationships (Tate 1987). Furthermore, organic matter contributes greatly to the soil's aggregate stability and its resistance to erosion (Morgan 1986).

Removal of livestock grazing pressure would likely result in increased vegetative cover and subsequent increases in plant litter over time. However, this "passive approach" would be a slow process, at best, and replenishment of diminished soil organic matter contents could take decades. Therefore, employment of a management practice which would immediately increase soil organic matter and improve the existing condition of the soil or vegetation (active approach) is preferred.

USDA Forest Service researchers have investigated the effects of municipal sewage sludge applications on soil chemistry, soil microorganisms, vegetation, and surface hydrology on degraded rangeland sites (Aguilar and Loftin 1992; Dennis and Fresquez 1989; Fresquez et al. 1990a, 1990b, 1991). Sewage sludge is an excellent choice for an organic soil amendment because it is readily available, contains comparably high levels of plant nutrients (particularly nitrogen and phosphorus), and has excellent soil-conditioning capabilities (Alloway and Jackson 1991; Glaub and Golueke 1989; Parr et al. 1989).

This paper presents research findings from two Forest Service studies on application of sewage sludge to semiarid rangeland (fig. 1). Sludge effects on soil, chemistry, vegetation, and surface hydrology are discussed.

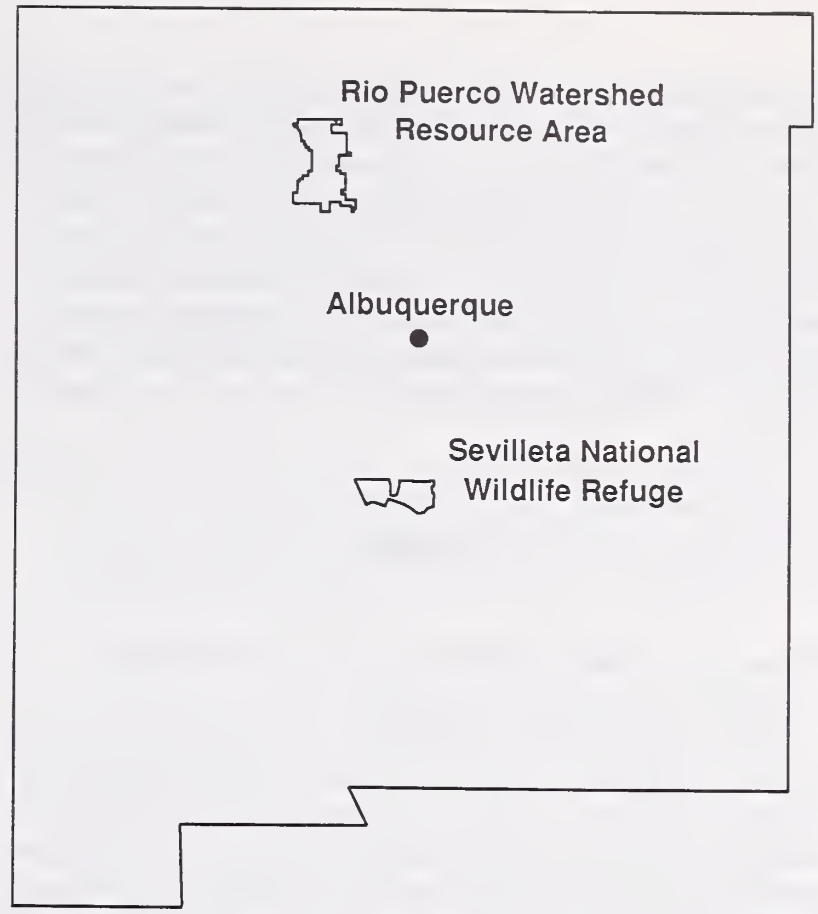

Figure 1. — Location of the two sewage sludge amendment studies on New Mexico rangeland. The Rio Puerco Watershed Resource Area (sludge application study) and the Sevilleta National Wildlife Refuge (sludge/hydrology study) are located approximately 100 km northwest and 120 km south of Albuquerque, respectively.

SLUDGE APPLICATION STUDY

USDA Forest Service scientists conducted the first in-depth study of the effects of sewage sludge application to degraded semiarid rangeland (Dennis and Fresquez 1989; Fresquez et al. 1990a, 1990b, 1991). Dried, anaerobically digested sewage sludge from the city of Albuquerque was surface-applied to a degraded, semiarid grassland site within the Rio Puerco Watershed Resource Area (fig. 1). The Rio Puerco basin, an extremely degraded watershed with a long history of heavy livestock grazing, is one of the most eroded and overgrazed river basins in the arid West (Sheridan 1981).

Sewage sludge was applied (one-time application) at rates of 1, 22.5, 45, and 90 Mg ha^{-1} (0, 10, 20, and 40 tons $acre^{-1}$ based on oven-dried weight) to each of 4 plots (3 m X 20 m) in a completely randomized block design containing a total of 16 plots. The site was characterized as a *Gutierrezia sarothrae/Bouteloua gracilis-Hilaria jamesii* (broom snakewood/blue grama-galleta) plant community on a moderately deep, medium-textured soil. The soil was classified according to Soil Taxonomy (Soil Survey Staff 1975) as a fine-loamy, mixed, mesic Ustollic Camborthid. Mean annual precipitation, measured at the site with a standard rain gauge through the duration of the study (June 1985 to September 1989), was approximately 250 m (Fresquez et al. 1991).

Field and Laboratory Methods

The area was fenced to exclude livestock and wildlife. Pre-treatment soil samples were collected at each of the 16 plots in June 1985. Post-treatment samples were collected in August of 1985, 1986, 1987, 1988, and 1989. Five randomly located subsamples from each plot were taken from the top 15 cm of soil with a 5-cm diameter bucket auger. To ensure collection of mineral soil only, sludge was brushed aside prior to sampling on treated plots. Subsamples were composite in sealable, sterile plastic containers, placed in an ice chest, and transported back to the laboratory where the soils were passed through a 2-mm

sieve. All 16 composite soil samples from each of the 5 sampling dates were analyzed for chemical and physical properties. Chemical characteristics of the applied sludge and the soils prior to the treatment are reported in Fresquez et al. (1991). Methods employed for other soil chemical tests and plant tissue analyses of vegetation collected from each plot are described in Dennis and Fresquez (1989). Statistical methods employed to test for differences in soil and vegetation properties among the various sludge application treatments are described by Fresquez et al. (1991).

Results

Changes in Soil Nutrients and Heavy Metals

Total nitrogen (TKN), phosphorus (P), potassium (K), and electrical conductivity (EC) increased with sewage sludge application during the study's first year (table 1). Soil organic matter in mineral soil below the sludge layer did not increase until after the fifth growing season. The delayed soil organic matter response was likely an indirect effect of the increased nutrient availability and below-ground plant and microbial productivity in response to the sludge amendment.

Soil pH dropped from 7.8 to 7.5 in the 90 Mg ha^{-1} treatment during the first growing season, and to 7.4 in the second growing season (table 1), probably due to slightly acidic leachates from the applied sludge (Fresquez et al. 1991). Acid-producing microbial reactions in the soil (i.e., nitrification) may have contributed to the decrease in soil pH. Soil pH continued to decrease in plots with the highest application through the 5-year study period. Metals generally become more soluble with decreased pH. Although soil pH decreased over time because of the sludge amendments, only diethylenetriaminepentaacetic acid (DTPA)-extractable soil copper (Cu) and cadmium (Cd) increased to concentrations slightly above desirable levels (>10 to 40 mg kg^{-1} Cu and >0.1 to 1.0 mg kg^{-1} Cd are considered phytotoxic and undesirable in the soil, Tiedemann and Lopez 1982), and this occurred only after the fifth growing season after applications of 45 Mg ha^{-1} or greater. Changes in other trace elements produced by the different sludge amendments are described in Fresquez et al. (1990b, 1991). The higher trace element concentrations resulting from the sludge amendments were probably directly related to sludge decomposition rather than to the solubilization of pre-existing soil micronutrients as a result of decreased pH (Fresquez et al. 1991).

Changes in Blue Grama Forage Production and Quality

Total plant density, species richness, and species diversity (index of numbers of different species in relation to the total number of plants per given area) decreased, while cover and yield of blue grama significantly increased on treated plots (Fresquez et al. 1990a). Normally, in the presence of stimulus (e.g., fertilization), plant production increases while the diversity of plant species decreases (Biondini and Redente 1986; Houston 1979). The positive effects of the sludge amendments on forage production are demonstrated by changes in blue grama production after the first, second, and fifth growing seasons

Table 1. — Changes in soil chemical properties on plots (n = 4 per application) treated with sewage sludge, Rio Puerco Watershed Resource Area, NM. [adapted from Fresquez et al. 1991]

Sludge application	Organic matter	TKN	P	Cd	Cu	EC	pH
(Mg ha^{-1})	(g kg^{-1})	----------	----------	mg kg^{-1}	----------	(dS m^{-1})	
			First growing season				
0	12 a	729 b[1]	5 c	0.01 a	1.04 c	0.36 c	7.8 a
22.5	13 a	817 ab	15 bc	0.01 a	1.19 bc	1.06 bc	7.7 ab
45.0	14 a	845 ab	20 b	0.01 a	1.60 ab	1.66 ab	7.6 b
90.0	12 a	924 a	31 a	0.01 a	2.10 a	2.23 a	7.5 b
			Second growing season				
0	14 ab	665 b	4 c	0.01 a	0.92 b	0.37 b	7.8 a
22.5	15 a	828 ab	20 bc	0.01 a	2.21 ab	0.96 ab	7.6 ab
45.0	15 ab	843 ab	44 b	0.02 a	2.99 a	1.26 ab	7.4 b
90.0	12 b	987 a	72 a	0.02 a	3.48 a	1.97 a	7.4 b
			Fifth growing season				
0	14 b	682 b	9 b	0.01 b	0.88 b	0.40 c	7.8 a
22.5	18 ab	890 b	26 ab	0.01 b	2.40 b	0.66 b	7.7 a
45.0	26 a	1869 a	42 ab	0.15 a	23.52 a	0.82 ab	7.4 b
90.0	23 ab	1814 a	57 ab	0.20 a	29.78 a	0.90 a	7.0 b

[1] Means within the same column and year followed by the same letter are not significantly different at the 0.05 level by Tukey's multiple range test.

(table 2). Blue grama production was significantly greater for all of the sludge amendments during the first and second growing seasons, with yields ranging from 1.5 to 2.7 times greater in the treated plots than in the unamended (control) plots. Summer precipitation during 1986 was exceptionally high and the highest yields of dry matter production occurred during this growing season. After the fifth growing season, blue grama production remained higher in the 45 and 90 Mg ha^{-1} sludge-amended plots, although the benefits of the added sludge had greatly diminished for the lowest (22.5 Mg ha^{-1}) sludge amendment.

Table 2. — Blue grama production (mean production and standard error, S.E.; n = 4) in control and sludge-amended plots after one, two, and five growing seasons, Rio Puerco Watershed Resource Area, NM.

Treatment (Mg ha^{-1})	Production (kg ha^{-1})	S.E.
First Growing Season, 1985	(precipitation = 147 cm)	
Control	270 b[1]	22
22.5	480 ab	96
45.0	433 ab	100
90.0	509 a	62
Second Growing Season, 1986	(precipitation = 239 cm)	
Control	392 b	76
22.5	575 ab	163
45.0	824 ab	114
90.0	1067 a	227
Fifth Growing Season, 1989	(precipitation = 201 cm)	
Control	281 a	39
22.5	291 a	75
45.0[2]	506 a	51
90.0	500 a	178

[1]Means within the same column and year followed by the same letter are not significantly different at the 0.05 level by Tukey's multiple range test.
[2]Significantly different from the control at the 0.10 level by Dunnett's multiple comparison test.

Although average blue grama production for the 45 and 90 Mg ha^{-1} treatment plots remained nearly double that of the control during the fifth growing season, within-treatment variation in blue grama production also increased, resulting in statistically non-significant differences ($\alpha = 0.05$) between the control and sludge-amended plots.

The sludge amendments also significantly increased the nutritional value of blue grama. Tissue N, P, K, and crude protein increased with the application of sludge to recommended tissue concentrations (Fresquez et al. 1991). Furthermore, most of the trace metals, including Cu and Cd, in blue grama plant tissue did not increase significantly during the 5-year study, thereby reducing concerns that these toxic elements could be transferred to grazing animals. This is a significant finding because concerns over heavy metal accumulations frequently limit sewage sludge application to land. Based on these cumulative results, Fresquez et al. (1991) concluded that a one-time sludge treatment ranging from 22.5 to 45 Mg ha^{-1} (10-20 tons acre^{-1}) would yield the best vegetation response without potential harm to the environment.

An unexpected benefit from the sludge treatment was a decrease in broom snakeweed—a toxic, non-palatable, competitive range plant (Fresquez et al. 1990a). The number of broom snakeweed plants in the sludge-amended plots decreased progressively over the 4-year period 1985-1988 following the addition of the various sludge treatments (table 3).

Table 3. — Mean density[1] of broom snakeweed (*Gutierrezia sarothrae*) in sludge-amended versus unamended plots (n = 4) on a degraded rangeland site, Rio Puerco Watershed Resource Area, north-central New Mexico. [adapted from Fresquez et al. 1990a]

Sampling Date	Sludge Amendment (Mg ha^{-1}) 0	22.5	45	90
1985	3.9	2.0	1.8	1.0
1986	3.4	2.0	1.5	1.0
1987	3.5	1.5	1.2	1.0
1988	2.7	0.1	0.0	<0.05

[1] Density values represent the number of plants per 0.5 m^2.

The exact mechanism(s) responsible for the decline of broom snakeweed remains unclear, but the decline in snakeweed was concurrent with an increase in production. Furthermore, broom snakeweed production between the sludge-amended plots, and on rangeland outside of the fenced study area, continued to flourish without visible decline throughout the 5-year study and to the present. This observed decrease in broom snakeweed within sludge-treated plots represents a significant finding in rangeland restoration research. Budd (1989) reported that broom snakeweed occupies over 16 million hectares in New Mexico, including over 62% of the state's grazing rangeland.

SURFACE HYDROLOGIC STUDY

A second study was established in spring 1991 within the Sevilleta National Wildlife Refuge (fig. 1). The objectives of this study were: 1) to determine if and how changes in vegetation following sludge application influence runoff and surface water quality, and 2) to assess the fate of potential sludge-borne contaminants introduced to the environment through the application. The Sevilleta Refuge, managed by the U.S. Department of Interior's Fish and Wildlife Service, provided an excellent opportunity to compare rangeland treatment effects because public access is restricted and livestock grazing is prohibited. Climate at the study area is arid to semiarid with mean annual precipitation ranging from 200 to 250 mm (Moore 1991). Within the study area, a blue grama/hairy grama (*Bouteloua gracilis/B. hirsuta*) dominated community was

selected for study on a moderately sloping (6%) and strongly sloping component (10-11%) of a stable alluvial fan. The deep, well-drained soils were characterized and classified according to Soil Taxonomy (Soil Survey Staff 1975) as fine-loamy, mixed, mesic Ustollic Calciorthids formed in local alluvium and colluvium derived from limestone and sandstone.

Field and Laboratory Methods

Six pairs of runoff plots, each pair consisting of a treated (sludge-amended) and a control (no sludge) plot were established within two hillslope gradient classes (three treated and control plots per slope gradient class). Runoff plot dimensions (3 X 10 m) were identical to those used by USDA Agricultural Research Service investigators involved in the Water Erosion Prediction Project (WEPP) (U.S. Dept. of Agriculture ARS 1987). Therefore, results from this study might be applied to WEPP models for larger-scale predictions on runoff and sediment yield for semiarid grasslands. The experimental plots were bordered by metal flashing to prevent external water from entering the plots. The borders direct internal surface runoff to the base of the plots during rainfall events, where the water is collected in sample reservoirs (Aguilar and Loftin 1992). Sludge was applied to the plots in April 1991. The treatment was a one-time application of 45 Mg ha^{-1} municipal sewage sludge (dry-weight basis) provided by the Albuquerque Public Works Department.

Total precipitation during summer storms was measured with two standard rain gauges (rainfall collection buckets) and a self-activating rain gauge that records data for calculating storm intensity (mm hr^{-1}). The runoff plots were subjected to simulated rainfall in September 1991 after the vegetation had an entire growing season to respond to the sludge treatment, and then again in September 1992 following two growing seasons. The simulator distributed water simultaneously to a plot pair so infiltration and runoff yield could be observed and recorded on the control and treated plots concurrently. Simulated rainfall input was equivalent to a high intensity summer thunderstorm common in the region (6-8 cm hr^{-1} for 30 minutes). Representative samples of the runoff water were obtained by manually stirring the contents in the collection reservoirs after each rainfall event, and were analyzed for nitrate-N and trace element content. Analytical tests followed standard procedures as outlined in Agronomy #9, Methods of Soil Analysis - Part II (page 1982) and U.S. Department of Agriculture Handbook No. 60 (Richards 1969). Pre-treatment soil and vegetation characterization established uniformity between control plots and those subsequently treated with sludge. Analysis of variance techniques were used to test for significant differences between the treated and control plots in runoff yield and trace elements.

RESULTS

Hydrologic Response to Sludge Amendment

First-year natural storm runoff was significantly less from sludge-amended plots than from control plots (fig.2). Runoff from control plots was 3.4 to 37 times greater than runoff from treated plots.

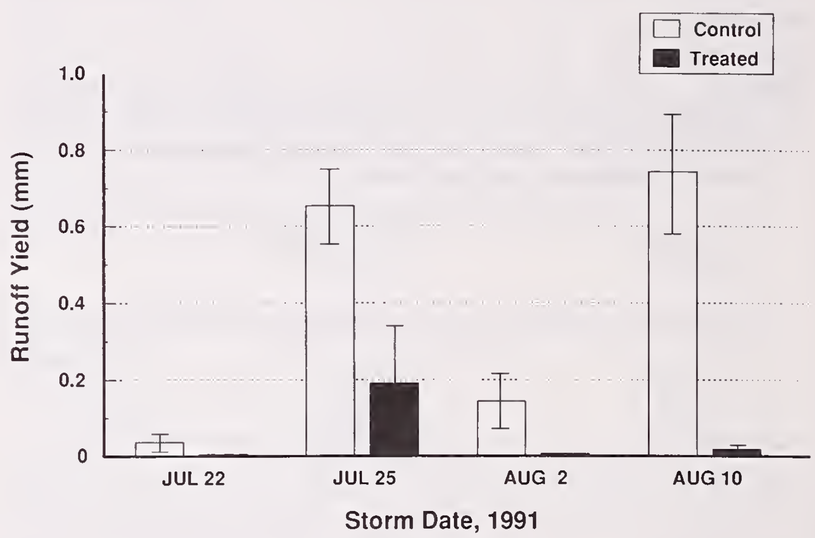

Figure 2. — Mean runoff from sludge-treated ($n = 6$) *versus* control plots ($n = 6$) during four natural storms, Sevilleta National Wildlife Refuge, 1991. Differences between control and treated plots were significant ($\alpha = 0.05$) for all storms.

Rainfall simulation experiments were conducted on the runoff plots in September 1991 (fig. 3). Although runoff yields from our control plots are comparable to runoff yields measured during studies conducted in rangeland elsewhere in New Mexico and Arizona (Ward and Bolton 1991), runoff from control plots greatly exceeded that from treated plots. Therefore, the hydrologic differences observed between our treated and control plots can be directly attributed to the sludge treatment.

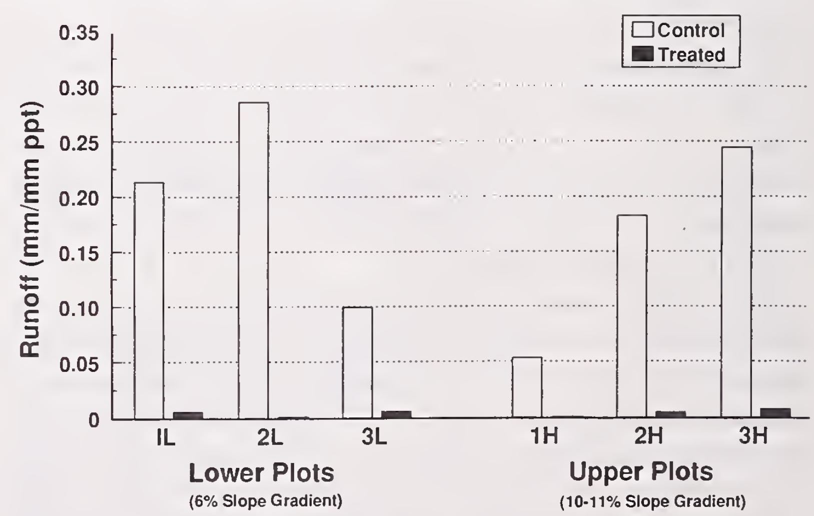

Figure 3. — Runoff yield from sludge-amended (treated) and unamended (control) plots during rainfall simulation experiments. Expression of runoff yield as runoff per mm of precipitation standardizes the runoff for comparison because precipitation input among and between plot pairs varied somewhat due to the occurrence of wind gusts.

The two factors we considered responsible for the reduction in runoff on treated plots were increased ground surface roughness and water absorption by the dry sludge. Through time, the sludge should decompose and have a less direct effect on surface runoff, but increased plant productivity and ground cover could act to reduce runoff yields from the treated plots.

Potential contamination of surface water by constituents in Albuquerque sludge does not appear to be a limitation for sludge application. Nitrate-N, Cu, and Cd concentrations in the runoff water were well below New Mexico limits for ground water and livestock and wildlife watering, both during natural and simulated rainfall. No statistical differences ($\alpha = 0.05$) in these potentially toxic constituents were found between the treated and control plots (Aguilar and Loftin 1992).

CONCLUSIONS

Sewage sludge amendments represent an active approach and a viable means of alleviating the damaging effects of heavy livestock grazing within southwestern public lands. Surface application of treated municipal sewage sludge has been shown to significantly increase both plant cover and total forage production. Furthermore, increased ground surface roughness and increased water-holding capacity of soil resulting from the sludge's mulching effect immediately reduce the potential for runoff and water erosion. Subsequent increases in vegetation cover due to the sludge's fertilizer effect should further improve the surface hydrology of treated lands. Potential pollution of surface water by sludge-borne contaminants in Albuquerque sewage sludge, including heavy metals, does not appear to be a problem with a one-time application of 22.5 to 45 Mg ha^{-1} (10-20 tons $acre^{-1}$). Similar results could be expected using comparable sewage sludge from other municipalities.

Sludge application to degraded sites in the Southwest has the potential for being environmentally and economically beneficial if application is based on sound guidelines developed through continuing research. It is reasonable to believe that degraded sites within piñon-juniper woodlands would respond favorably to surface applications of sewage sludge, as the understory and inter-canopy vegetation is similar to that found in adjoining semiarid rangeland habitat. However, much research is needed to establish the dynamic relationships among inter-canopy vegetation, understory vegetation, and the trees themselves in these woodlands in response to sludge-induced increases in nutrient availability and improved soil/water relationships.

ACKNOWLEDGMENTS

Portions of this research were conducted in cooperation with the USDI Bureau of Land Management. The hydrology study was funded by the 1991 New Mexico Water Resources Research Institute (WRRI) - Chino Mines Company Grant Fund and the 1992 WRRI General Grant Program. We would like to thank Dr. Timothy Ward and Dr. Susan Bolton, Department of Civil, Agricultural and Geologic Engineering, New Mexico State University, for their assistance with the rainfall simulation experiments. We also thank the city of Albuquerque for providing and transporting the sludge to study sites.

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Management Implications for Mule Deer Winter Range in Northern Piñon-Juniper

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Abstract — During the next few years, the piñon-juniper woodlands in the Zuni Mountains of New Mexico will present many management opportunities and challenges. Mule deer winter range, which often limits carrying capacity, can benefit greatly from attention and funding if management tools are carefully chosen. Fuelwood harvest openings should be designed for deer needs. Areas containing sagebrush, bitterbrush and cliffrose should not be burned unless excess winter range is present. Winter areas should be enhanced or rehabilitated by interseeding, by using soil amendments, by using "soft" mechanical browse treatments or by grazing management. Understanding piñon-juniper/shrub ecology is necessary in order to select key habitat sites to treat so that resources will be well spent.

INTRODUCTION

The Zuni Mountains in New Mexico are much like other areas of the western United States. This area has an abundant supply of piñon-juniper woodlands that are presenting many opportunities and challenges for multiple resource management. One Zuni Mountain resource is a highly prized mule deer herd. Numerous years of study and intense harvest management by the New Mexico Department of Game and Fish, and habitat management by the U.S. Forest Service have produced an area with good numbers of deer and trophy bucks. This deer herd represents an economic asset to the state and has a high public profile. It is highly desirable that habitat quality for these deer be maintained and/or enhanced where possible. Habitat enhancement for this herd has been targeted by Habitat Stamp (Sikes Act) monies and Forest Service Land Management Plan guidance.

One chronic limiting factor for mule deer populations in the western United States is shortage of winter range. Many things contribute to the shortage such as historical influences, forage user conflicts and human encroachment. The Zuni's follow the norm in this respect. In the West, large amounts of deer winter range are located within the piñon-juniper belt and this is the case in the Zuni Mountains. Management in the piñon-juniper ecosystem presents one of the most significant potentials for habitat maintenance and improvement possible for the Zuni Mountain deer herd. Understanding piñon-juniper community ecology and selecting the correct area and tools for management of these winter ranges is essential, or at best, efforts will not be well directed. At worst, a winter range can be rendered nearly useless for a long period of time.

DEER POPULATIONS vs. PIÑON-JUNIPER SUCCESSION

Part of the management of a deer winter range entails understanding the relationship habitat has with deer numbers. Pinyon-juniper habitats comprise the majority of mule deer winter ranges in the areas where these habitats occur. The trees provide horizontal and vertical thermal cover during the winter. The plant communities associated with these trees can provide nutritional maintenance for mule deer throughout the winter months. Few other habitats can do this.

But for every positive, there is a negative. As plant community succession progresses in a woodland system, piñon-juniper naturally begins to effectively crowd the understory vegetation needed by the deer. Trees can invade rangelands. The trees intercept water and minerals needed for understory production. Pinyon and junipers release allelopathic chemicals that inhibit seedling growth of understory species. By the time a piñon or juniper tree is 3-6 feet tall, understory herbage production can be reduced by 30% (Tausch 1979).

If herbage production is reduced, deer carrying capacity is also greatly reduced over time. In most areas, deer do not have other habitats for winter use because the forage is not available or is not nutritional, or thermal cover is not available. Many

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times, housing developments and roads crowd into winter ranges at lower elevations. Deer numbers simply adjust to a lower optimum number with amounts of winter range becoming the limiting factor of carrying capacity.

In the 1980's a study was conducted on a mule deer herd located on the western edge of the Colorado Plateau region. This herd had experienced steady population declines since the 1960's. The decline in deer numbers was highly correlated to the closing canopy cover of the piñon-juniper, its expansion into areas formerly devoid of trees, and the corresponding decline in understory production. The study found that when the deer herd experienced a natural dip in population numbers, piñon-juniper succession reset the high end carrying capacity at a lower level. Each time the herd recovered from a natural decline, numbers were still less than the preceding high number. This herd declined in number to the point to where poaching and predation could also exert a suppressing influence on the numbers (Suminski 1985).

This same phenomenon can work sooner or later throughout all of the piñon-juniper belts in the west, including the Zuni Mountains. On one hand, piñon-juniper habitat is needed to provide a superior wintering area for deer. Yet, this habitat type can also impact deer herd carrying capacity in a negative manner. The field biologist must follow a fine line of management in this habitat type so that maintenance or expansion of the winter range is achieved and carrying capacity is not reduced even for a few years. This calls for the biologist to have a thorough understanding of the vegetation communities, management tools and potential results of management when tackling the piñon-juniper belt. The remainder of this paper will focus on some of the ecological factors and management tool implications that must be considered for the Zuni Mountains.

THE ECOLOGY

One unique fact about the Zuni Mountains is that the entire area is located within the Colorado Plateau physiographic region (fig.1). This fact makes the Zuni Mountains more closely related ecologically to southern Utah and western Colorado than to southern portions of New Mexico and Arizona at lower elevations (Van Devender 1991). One other striking thing about the Zuni Mountains is that large numbers of deer winter in the piñon-juniper belt located on the west side of the Continental Divide. There are a couple of small wintering areas on the north and south sides of the area east of the Divide, but these are not significant.

The west side is so significant that the New Mexico Department of Game and Fish, in conjunction with the Forest Service, has established a designated winter range. It is known as the Ft. Wingate Habitat Protection Area (HPA). Many deer spend parts of the winter here as well as along the border areas between Zuni Reservation and the Forest Service's southern boundary.

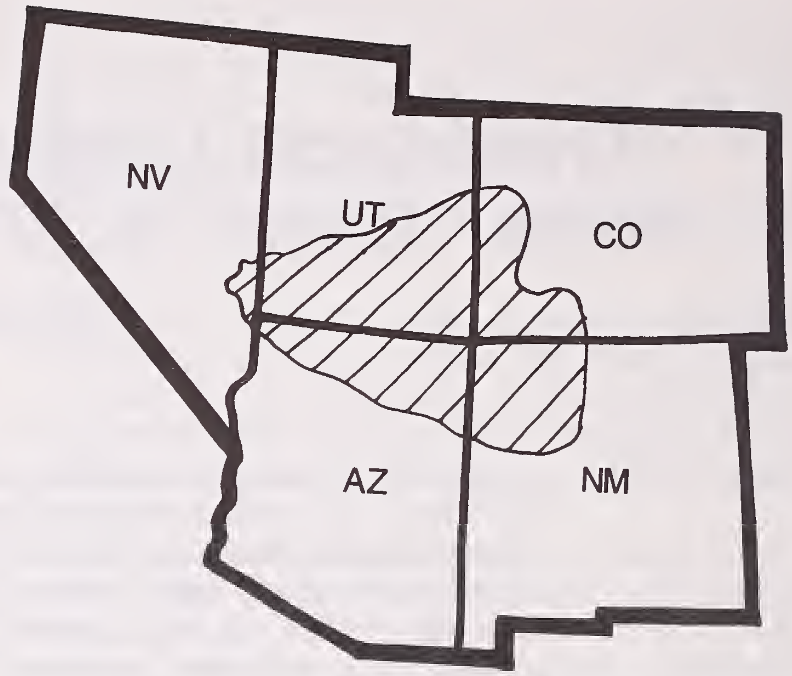

Figure 1. — The Colorado Plateau physiographic region (Van Devender 1991).

People ask why the HPA, and the entire west side of the Zuni's for that matter are so special. One place to look for a somewhat simple explanation is the Soil Conservation Service Major Land Resource Classification and subresource area system. Some of the deer winter range east of the Divide is comprised of a true woodland with cliffrose, mountain mahogany and gambel oak for deer winter use. But much of the east side is comprised of a grassland, mixed shrub site. On this site, piñon-juniper is part of a shrub community with grasslands in the openings which form a savannah-like area where blue grama and grama/black sagebrush dominate the open areas. Some might argue that much of this is an invaded rangeland.

The west side of the Divide is made up mostly of a true woodland site (USDA 1992a). On this site, shrubs, trees and grasses are more intermixed. Here, piñon-juniper dominance represents the late seral stage. The explanation for this slight difference is the fact that the Continental Divide creates a rainshadow in the Zuni Mountains. The rainshadow causes winter precipitation to be used efficiently and this is influential on the vegetation (Park 1992).

Savannah and woodland piñon-juniper habitats are slightly different, ecologically. Many favored deer winter forage species such as bitterbrush, cliffrose, and mountain mahogany occur on both sites, but only the sites on the west side of the Divide contain big sagebrush, Artemisia tridentata tridentata, Artemisia tridentata wyomingensis and Artemisia tridentata vassayana (USDA 1992a).

The Forest Service habitat typing system breaks the west side sites down into habitat types such as Pinyon/Big Sagebrush, Pinyon/Cliffrose-Big Sagebrush phase and One-seed Juniper/Big Sagebrush (USDA 1987). (The FS Terrestrial Ecosystem Survey will further describe these areas when published.) If a site is Pinyon-Juniper-Big sagebrush as opposed to Pinyon/Blue Grama that does not contain big sagebrush, it may not make any appreciable difference in terms of management applications for

most resources such as pine nut production or fuelwood management. But to one resource, the mule deer herd, the piñon-juniper habitat type that contains big sagebrush makes every difference. The difference lies in nutrition. Only the sites on the west side of the Continental Divide provide the potential for superior mule deer winter range that deer will readily select. Table 1 shows nutritional aspects of several key winter forage shrub species.

Table 1. — Winter nutritional values of key deer winter shrub forage species compared to minimum values needed to maintain mule deer in winter (Welch 1986).

	Minimum Values Needed			
	50.0% In vitro Digestibility	7.0-8.0% Crude Protein	0.18-0.28% Phosphorus	2.0 mg/kg Carotene
Plant Name	Values Present			
Big sagebrush	57.8	11.7	0.22	17.6
Black sagebrush	53.7	9.9	0.18	8.0
Rubber rabbitbrush	44.4	7.8	0.14	-
Fourwing saltbush	38.3	8.9	-	3.1
Cliffrose	37.6	8.6	-	-
Forage Kochia	32.2	7.2	-	-
Gambel oak	26.6	5.3	-	-
True mountain mahogany	26.5	7.8	0.13	-
Antelope bitterbrush	23.5	7.6	0.14	-

Values for forbs and grasses found on these woodland sites were omitted as none, with the exception of fall regrowth of Desertorum crested wheatgrass, provide ideal nutrition. Also, grasses and forbs are often buried under snow and are unusable to deer in deep winter. Only two species of vegetation associated with Zuni piñon-juniper winter range contain the nutritional elements necessary to maintain deer in good condition over the winter. Black sagebrush, which occurs on the east side of the Divide, is one. Deer will eat black sage during a hard winter and I have worked in an area where black sage ranges were designated alternate key deer winter range. But studies of forage preference among sage species indicate that black sagebrush, at 17% use, is a distant fourth for mule deer preference compared to big sage at 30-50% (Wamboldt 1993). Half of the small deer winter ranges on the east side of the Divide are associated with black sage sites. Cliffrose, mountain mahogany and oak grow in the woodlands adjacent to the black sage savannahs. The problem is that deer have to travel quite a distance to reach either area and snow is often deep in the upper woodland. Large amounts of energy can be expended reaching nutritional forage and ice cream plants like cliffrose which do not grow intermixed with black sage. That leaves big sagebrush, on the west side of the Continental Divide, to provide a nutritionally complete, readily accessible winter diet. Not only is the big sagebrush nutritionally superior, with some varieties preferred by deer, but many of the habitat types containing big sagebrush also contain ice cream plants such as cliffrose mixed right with the big sagebrush. In some areas, big sagebrush and cliffrose occupy swales while mahogany, oak and cliffrose can be found on adjacent rocky slopes. Deer do not have to expend a large amount of energy to eat well.

There are not large numbers of these big sagebrush sites on Forest Service lands in the Zuni Mountains, and those that occur are subject to invasion by piñon-juniper. These sites are in various stages of succession and condition. A few of the communities have good production levels and diversity of forage. Many of the sites that have big sagebrush as a component of the vegetative community have sparse understory and trees increasing in density and canopy cover (Blaisdell 1982). These Zuni Mountain habitat types, with big sage as a component of the community, represent priority areas for management. Attention must be directed to the management tools that will achieve the best results for wintering deer in these key areas of piñon-juniper/shrub habitat types.

THE MANAGEMENT TOOLS

Region 3 has a strong Pinyon-Juniper Initiative promoted by the Regional Forester. This means that in the years ahead, many Ranger Districts located in the piñon-juniper belt will have increased emphasis on management of these areas. This is a double-edged sword for the Zuni Mountain deer winter range. Funds and effort will be directed at improving watershed, forage, fuelwood harvest opportunities and a host of other things within the piñon-juniper belt. But not every management tool available will be good for key deer winter areas.

Take a look at fuelwood harvests within the deer winter range. Fuelwood harvesting can be a fine way to create openings. But, a situation cannot exist where every tree is removed. This would eliminate critical thermal cover in winter. If deer have to stay on a winter range with little cover, these animals will use more forage to stay warm and vegetation can easily be overused. If overuse occurs, condition of the area will decline over time. If deer are forced to move into areas where cover is adequate, but forage is not, overwinter mortality will rise.

Opening areas of piñon-juniper can be beneficial for a deer winter range by reducing competition and allowing good forage plants to grow naturally or from seeding. Research has shown that mule deer will not use areas over 1/8 of a mile from cover

in winter (USDA, 1992b). Tree removal should not be done in blocks wider than 1/4 mile, i.e. 1/8 mile combined for each of two possible edges. Tree removal could extend as far as was desired in length. An area in the Zuni's has been specifically designed to be fuelwood harvested in order to benefit mule deer (fig.2). Harvest areas are long and narrow. Cover areas are 50+ acres, edges are feathered and natural travel corridors have cover left intact. Treatment will be done on the tops of fans, not on steep slopes. The visual quality of this harvest will be pleasing.

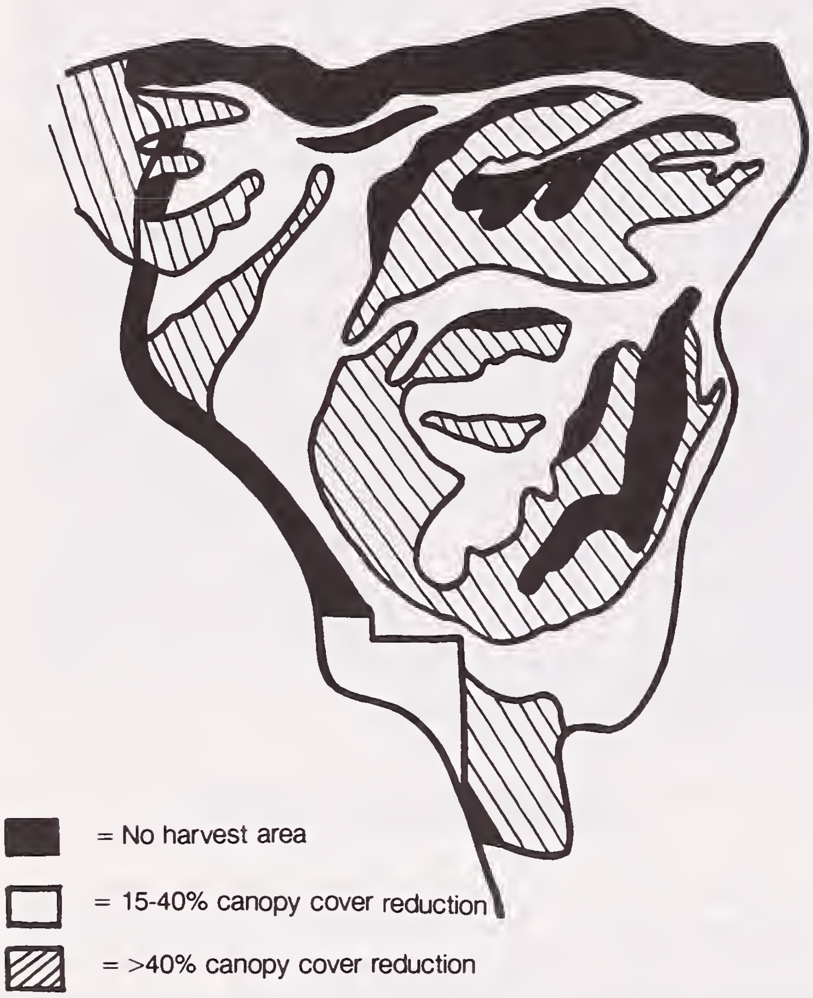

Figure 2. — Piñon-juniper fuelwood harvest area designed to benefit mule deer winter range in the Zuni Mountains, New Mexico.

When harvestable wood has been removed, it might seem desirable to burn the area in order to kill young trees and increase understory production within these open areas. Below the Mogollon Rim, browse is regularly rehabilitated using prescribed fire (Severson and Rinne 1986). In the Colorado Plateau, it would seem that thick herbaceous vegetation, such as big sagebrush, with high oil contents could carry a fire well. Research indicates this might not be so good from a soil temperature and nitrogen/phosphorus level standpoint (USDA 1992b). The biologist needs to take a very good look at the understory and determine the key forage plants for wintering deer. If oak or mountain mahogany were the only key shrubs, a properly timed burn could enhance these plants (USDA 1992c).

If sagebrush, bitterbrush or cliffrose are key winter forage species, burning these will nearly eliminate the present carrying capacity of the key deer winter range and it can take 15 years or longer for it to recover. Fire research conducted in Regions 3 and 4, and New Mexico Forestry, support the finding that sagebrushes do not resprout well. Bitterbrush is a very weak sprouter and has a good chance of dying completely within a few years. Cliffrose can sprout the first year and be entirely gone within 3-4 years (FEIS 1992; NM Dept. of Energy, Minerals and Natural Resources 1992; Fraas 1993).

If a fire is very cool and creeping, mountain big sagebrush seedlings can be quite abundant. But even in a cool fire, seed response can be widely variable in bitterbrush and cliffrose (Severson and Rinne 1988). However, starting from seed, the winter range will not have an appreciable carrying capacity for many years. If there are excess acres of winter range available over the present carrying capacity for wintering deer, burning the excess big sagebrush could be acceptable. In the Zuni Mountains, there is no excess.

If fire is not a preferred tool, how are these key deer winter piñon-juniper shrub communities to be maintained for vigor and production? It is known that if deer use is excessive, sagebrush seed heads will be eaten and the sage stands will have a hard time reproducing. Excessive deer use (exceeding 40% current year's growth) will reduce plant vigor and reproductive capacity in bitterbrush (Blaisdell 1982). Deer utilize bitterbrush in late summer when protein contents are high and can deplete winter supplies (Austin and Urness 1982). Livestock seek bitterbrush seeds when these are ripe in late summer (Guinta 1978). Livestock will eat young cliffrose in winter. Cliffrose also has a tendency to become arboreal with new leaders far out of the reach of deer.

Management recommendations have been researched and made for deer winter ranges in the Colorado Plateau and Intermountain areas where piñon-juniper shrub communities are critical for wintering mule deer (Blaisdell 1982). Those recommendations, which would apply to key Zuni deer winter ranges, are as follows:

1. Deep, fertile soils with 10+ inches of rainfall are preferred sites to treat either with changes in grazing management or selective plantings or other treatment.

The black sagebrush winter areas on the east side of the Continental Divide only receive about 6 inches of effective precipitation. The key winter areas west of the Divide managed by the Forest Service receive in excess of 10 inches of effective precipitation. Many big sagebrush sites that would be ideal for treatment are located on deeper soils in valleys. Cliffrose and bitterbrush have been successfully established in the Zuni Mountains on moderately deep soil sites. Properly timed

livestock grazing at moderate levels can be very compatible with winter range management. Browse stands can be rehabilitated and maintained using proper livestock management.

Alternate methods of browse rehabilitation may be tried. One Great Basin deer winter range consisted of over 1000 acres of Stansbury cliffrose, most of which was becoming arboreal with leaders high above deer reach. On a five acre plot, the oldest, most decadent plants were manually pushed and torn apart. Even though the wood was split, much of the woody stem remained in the ground. Leader growth was stimulated along the branches that lay on the ground during the first year. Growth was still taking place the second year after treatment. This rehabilitation method is fairly inexpensive and may hold promise.[1]

2. Competition from existing vegetation must be light enough to allow successful establishment of seedlings.

Removal of competing piñon-juniper aids in the reestablishment of all key browse species. Thick stands of big sagebrush must be treated to reduce competition. Interseeding seems to be the best method since carrying capacity should not be impacted by eliminating large block of sage. Scalpers on drills, or an "interseeder" implement, can clear a swath of vegetation a couple of feet wide. Seeds or seedlings are placed into the interspace, and new plants can become established.

3. A productive stand should have at least one desirable shrub and 10 desirable herbaceous plants per 100 ft^2. An ideal sagebrush site would have about 30% of the total vegetation in perennial forbs and grasses with sagebrush being somewhat scattered. Mixtures of species should be encouraged rather than monocultures. Revegetation may be necessary to obtain this mix.

If seeding of shrubs is indicated to achieve a proper balance and mix of vegetation, cliffrose, sagebrush and bitterbrush would be key shrub species to plant in the Zuni Mountains. Two preferred ascensions of big sagebrush are available, the Hobble Creek variety for more moist upland sites and the Gordon Creek variety for drier, lowland sites (Welch 1986; Welch 1992). The nutritionally superior Hobble Creek ascension of big sage has been used in New Mexico in the Colorado Plateau Region with good success. Seed can be drilled, broadcast, transplants or Mother plants can be used. Bitterbrush can be difficult to seed. Cache planting of scarified seed, placing 5-6 seeds in a small hole in ideal soil, seems to be one somewhat successful method. Transplanting of seedling stock can be somewhat successful. Cache planting of cliffrose might be the best method on rocky sites, but cliffrose has been successfully seeded onto the west side of the Zuni's using only a small drill.

Other species that work well when seeded into these piñon-juniper shrub sites include small burnet, winterfat, bottlebrush squirreltail, Indian ricegrass, Lewis flax and prostrate Kochia. The last specie, Kochia prostrata, seeded at about 1.0 pounds per acre, is an excellent forage species that grows quickly and does not invade healthy communities of slower growing native shrubs (USDA 1993). Kochia has been successfully planted in the western portion of the Zuni Mountains.

When a person is using shrub seed as well as selected grass and forb seed to rehabilitate a winter range, the price becomes very steep, very quickly. Therefore, the seeding efforts must be successful in order to protect the investment and to help the deer resource. Some techniques are being done to enhance success.

On Zuni winter areas, grasses and forbs will be strip seeded with shrubs in order to reduce competition. Grass and forb rows will be planted 12-24 inches from shrub rows (Monsen and Shaw 1982). Finely crushed peanut hulls will be added to fine grass and forb seed. These inexpensive, inert particles prevent separation of seed species by size and weight. Application of seed is more uniform and species are spread more evenly.

Wetted carbonate polymer crystals will be added to shrub seeds, bare root stock, and rooted cutting plantings. This inert material holds water within its walls and releases it only when the plant root draws it out. Small amounts are released over time, allowing a seedling to become well established no matter what climatic conditions occur. Several shrub seeds and the added polymer will be cache planted rather than broadcast or drilled. This polymer product is being used widely in commercial private agriculture to cut down on irrigation costs and has worked very well.

One last significant point must be made concerning management of the mule deer winter range in piñon-juniper.

4. Revegetated areas must be properly managed.

New seedlings must be protected from excessive use. Livestock may need to be excluded until new plants are well established and then regulated to maintain vigorous stands. Grass and forb utilization should be no more than 40%. No more than 40% of current year's growth can be taken for shrubs to survive. If treated areas are small, deer utilization may be a problem and an aid such as a solar electric fence might be indicated. These fences are effective as long as the fence is "hot" from the first day of construction onward.

1 Suminski, R. unpublished data located at Humboldt National Forest, Ely Ranger District, Ely, NV.

Additionally, one of the unfortunate things about piñon-juniper/shrub communities is that these are always quite dynamic. An ideal winter range with a good proportion of forage shrubs with a few trees mixed in for cover is unstable. The trees naturally increase in number and canopy cover, trying to reach potential natural community as succession occurs. The land manager must try to maintain a high-mid seral stage of succession. For this reason, removal of whips and encroaching trees is a necessity, but can be a never ending job in this habitat type. The 3-6 foot trees, that begin to affect understory may not desirable firewood trees. This leaves the use of manual methods to cut these out of a winter range area. This is part of the cost of maintaining or enhancing a critical winter range.

SUMMARY

Historical accounts and researchers state that the piñon-juniper ecosystem has been a part of the Zuni Mountain system for hundreds of years (Van Devender 1991). Climatic changes and Post-Anglo influences common to the west such as grazing changes, fire suppression and clearcutting all shaped the piñon-juniper system that is present today in the Zuni's.

The piñon-juniper habitat type is very important for wintering mule deer. The condition of this habitat can determine the number of deer an area is able to support. When trying to determine where effort should be expended for winter range enhancement, several basic facts must be known. Winter concentration areas of deer must be delineated. Key forage species must be identified.

In the Zuni Mountains, which are located in the Colorado Plateau physiographic region, habitat types containing big sagebrush make up nutritionally superior winter range which should be targeted for management. The ecology of piñon-juniper and related understory vegetation must be understood because some management tools are beneficial and some can be detrimental to this habitat type.

Fuelwood harvests can be done in a manner to enhance deer range by keeping cutting areas away from steep slopes, and by keeping cutting areas long and narrow with feathered edges. Whips must be removed to prevent competition with desired herbaceous vegetation. Burning in these harvest areas or on winter ranges containing bitterbrush, sagebrush or cliffrose is not desirable since none do well as sprouters. However, many of these plant communities need treatment to restore diversity, vigor and/or production.

Treatment sites with the best soils and precipitation regimes should be chosen. Competition from plants in the existing community must be reduced to allow new plants to establish. A good winter range should be brought to the point where one desirable shrub and 10 desirable herbaceous plants occur every 100 ft2. Rehabilitated areas must be properly managed for desired grazing utilization.

Some techniques may help reduce costs of winter range rehabilitation and/or enhance success. Strip seeding grass, forbs and shrubs can reduce competition and give each a good start. Inexpensive additives can aid in broadcast seed distribution. Soil amendments such as carbonate polymers can provide moisture to seedlings until these are established.

Mule deer winter ranges such as those found in the piñon-juniper habitat type of the Zuni's are continually changing. Natural succession in these winter ranges, via increasing piñon-juniper influence, tends to reduce the total amount of ideal winter range available and thereby reduce deer carrying capacity. If these habitats are to carry the present number of deer, or an even greater number, aggressive management is a given. Many of the techniques talked about are labor intensive and fairly expensive, but from some of the material presented, one can see there is no half-way, cut-rate method of managing these key deer ranges. Because of the costs, priority management areas must be identified. Plant community ecology within the piñon-juniper habitat types must be understood to ensure that efforts are well spent.

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Occurrence and Control of Piñon Pine, Alligator Juniper, and Gray Oak Sprouts and Seedlings Following Fuelwood Harvest

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Abstract — Three experimental plots (12 x 25 meters) were located in each of four blocks (12 total plots) on a uniform southwestern exposure. Four of the plots were left undisturbed as controls. Four of the plots were clearcut in June 1989 and burned 4 months later in October 1989 (Treatment 1). Four of the plots were clearcut in June 1989 and burned 28 months later in October 1991 (Treatment 2). In July 1992, sprouts and seedlings were counted and heights measured in each plot. None of the piñon pine stumps sprouted, 47% of the alligator juniper stumps sprouted, and 90% of the gray oak stumps sprouted. Treatment 1 resulted in 50% of the alligator juniper sprouts being killed and none of the gray oak sprouts being killed. Treatment 2 resulted in only 10% of the alligator juniper sprouts being killed and 17% of the gray oak sprouts being killed. The control plots gained the equivalent of eight new alligator juniper seedlings per hectare from seeds by 1992, while the plots in Treatment 1 had no new alligator juniper seedlings, and the plots in Treatment 2 had 17 new alligator juniper seedlings per hectare. The control plots gained the equivalent of 608 new gray oak seedlings per hectare from seeds by 1992, while the plots in Treatment 1 had 133 new gray oak seedlings, and the plots in Treatment 2 had 492 new gray oak seedlings per hectare. Only 50 mature gray oaks per hectare were found in the control plots, which indicates that most seedlings do not become mature plants.

INTRODUCTION

Piñon pine and juniper species have similar ecological requirements and tolerances, which allows them to grow as dominants on many rangelands of the western United States. They are usually found as climax species on rocky hillsides and invade downhill onto flood plains, piedmonts, and valley bottoms and uphill onto mesa tops. Prior to settlement by Europeans, these invaded lands were burned from wildfires that killed most of the invading plants. Occasionally, the wildfires missed a plant, which resulted in a widely scattered savannah.

With the cessation of fire, these invaded lands experienced loss of the shrub, grass, and forb components, which resulted in accelerated erosion of the deep soils in the interspaces between trees. Archeological sites are adversely affected by the erosion and wildlife habitat is lost due to and abundance of trees and a suppression of understory food sources. Failing to stop the invasion or return the lands to a state of sustainability is a gross violation of the federal Clean Water Act. Programs to control the invaded piñon pine and juniper trees have included burning, mechanical, chemical, biological, and fuelwood harvest methods. Following control, sprouts from stumps and new seedlings rapidly appear, which give a need for follow-up and maintenance to prolong the life of the original control treatment. The objectives of this research project were:

1. To determine the number and height of sprouts and seedlings following fuelwood harvest of a piñon pine and juniper dominated mesa top site

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2. To determine the effects of fire for sprout and seedling control

METHODS

Site Location

The study was located in a commercial fuelwood harvesting area of the piñon pine - juniper woodland on the edge of Spring Mesa adjacent to Corduroy Canyon, which are between Winston and Beaverhead in the Gila National Forest. Specific location is Section 36, T9S, R12W, Catron County, New Mexico. The mean elevation is 2245 meters.

Soils on the study site are Lithic Haplustalfs. The vegetation of the study area consists of a moderately low tree density of two-needle piñon (*Pinus edulis*) (440 trees per hectare), alligator juniper (*Juniperus deppeana*) (167 trees per hectare), and gray oak (*Quercus grisea*) (69 trees per hectare). The understory herbaceous growth comprises a variety of grass and forb species. Among grasses, the most plentiful species is blue grama (*Bouteloua gracilis*). Mountain muhly (*Muhlenbergia montana*), wolftail (*Lycurus phleoides*), and squirreltail (*Sitanion hystrix*) are the other commonly found grasses. Goldeneye (*Viquiera dentata*), Bahia spp., and a few chenopods are some of the eye-catching forbs in the area.

Treatments

Three experimental plots (12 x 25 meters) were located in each of four blocks (12 total plots) on a uniform southwestern exposure. Four of the plots were left undisturbed as controls. Four of the plots were clearcut in June 1989 and burned 4 months later in October 1989. These plots had experienced one growing season to obtain favorable understory response, and the slash was dry. Four of the plots were clearcut in June 1989 and burned 28 months later in October 1991. These plots had experienced three growing seasons which resulted in much more favorable understory response but also taller sprouts. The purpose of the burning was to control stump sprouts. In July 1992, sprouts and seedlings were counted and heights measured in each plot.

RESULTS

Sprouting

None of the piñon pine stumps sprouted, 47% of the alligator juniper stumps sprouted, and 90% of the gray oak stumps sprouted. This experiment was spatially replicated but not temporally. Because 1989 was a drought year, these percentages may be lower than sprouting percentages in wetter years.

Sprout Mortality From Burning

Burning 4 months after clearcutting resulted in 50% of the alligator juniper sprouts being killed and none of the gray oak sprouts being killed.

Burning 28 months after clearcutting resulted in only 10% of the alligator juniper sprouts being killed and 17% of the gray oak sprouts being killed.

Sprout Heights Following Burning

Burning at 4 months after clearcutting resulted in shorter alligator juniper sprouts at 36 months post-clearcut than alligator juniper sprouts that were allowed to grow for 28 months (Table 1). The difference was a significant 59%. Gray oak sprout heights were not significantly different at 36 months when burned at 4 months after clearcutting and 28 months after clearcutting.

Table 1. — Sprout heights (cm) 36 months after clearcutting for fuelwood.

	Control	Burn at 4 months after clearcut	Burn at 28 months after clearcut
Piñon pine	0[1]	0	0
Alligator juniper	0[1]	22	35
Gray Oak	0[1]	94	89

[1] No stumps present

Seedling Density

Most new seedlings occurred in the control plots (Table 2). In all three treatments, gray oak seedlings were the most common. Burning at 4 months after clearcutting resulted in no new piñon pine and alligator juniper seedlings while burning 28 months after clearcutting resulted in significantly more than burning at 4 months.

Table 2. — New seedlings (number per hectare) 36 months after clearcutting for fuelwood.

	Control	Burn at 4 months after clearcut	Burn at 28 months after clearcut
Piñon pine	33	0	8
Alligator juniper	8	0	17
Gray Oak	608	133	492

Seedling Heights Following Burning

Piñon pine seedling heights were 77% greater in the controls and 64% greater in the burn at 28 months after clearcut treatment than alligator juniper seedling heights (Table 3). Heights for all species increased with time to burn, and seedling heights in the treatment that was burned 28 months after clearcutting were significantly greater than the controls.

Table 3. — New seedling heights (cm) 36 months after clearcutting for fuelwood.

	Control	Burn at 4 months after clearcut	Burn at 28 months after clearcut
Piñon pine	16	0	46
Alligator juniper	9	0	28
Gray Oak	17	28	37

CONCLUSIONS

Piñon pine did not sprout after clearcutting. Half of the alligator juniper stumps sprouted, and most of the gray oak stumps sprouted.

The highest mortality of alligator junipers (usually a desirable goal) and the lowest mortality of the gray oak (also usually a desirable goal) is best achieved 4 months after clearcutting. But a companion study showed the understory had not responded enough in the first growing season to adequately protect the site from erosion following burning. Therefore, burning to control sprouts was not found to be favorable.

Burning was not a useful tool for controlling alligator juniper sprouts. Alligator juniper sprouts grew faster than new seedlings.

OTHER CONSIDERATIONS

Re-establishment of piñon pine, if desirable, might be accomplished by leaving a branch attached to the stump.

Unwanted sprouts and seedling may be individually controlled with herbicides where permissible.

Or they might be controlled by individual treatment with flammable liquids when fuel conditions are so wet that grasses and forbs will not burn.

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Piñon-Juniper Guild Associations: A Presentation to the State Land Office Conference on Piñon Management

Ben Haggard[1]

The following observations are based on many years as an amateur naturalist, living in northern New Mexico. I design landscapes--more an art than a science. My desire to understand and become proficient with my media, in this case the species which occur naturally in my region, has led me to study native plants and their associations fairly carefully.

For the last three years I have been engaged in developing a twenty acre private botanical garden at Sol y Sombra, the home of Beth and Charles Miller on the outskirts of Santa Fe, New Mexico. This twenty acre site is layed out using the principles of permaculture, an ecological design system invented by a team of Australian ecologists in the early seventies. The garden contains several key elements, including extensive collections of ornamental and useful plants, a small organic farm, plantings and habitat for wildlife, and fifteen acres of ecological restoration work.

Several core ideas characterize permaculture. Natural processes are understood as flow events moving through the landscape. Wind, sun, water, migration of plants and animals, movements of capital, human populations, and automobiles--these are all flows which modify landscape. Ecological or holistic design attempts to work with these flows, directing them to systemically beneficial ends.

Permaculture recognizes the need for understanding and utilizing connection when designing or managing systems. Most natural systems depend on cooperation and mutually beneficial association for their function. Stability derives from the diversity of connections existing between members of natural communities. (The same principles describe human communities, a subject beyond the scope of this discussion.)

This leads to the concept which I specifically want to introduce--guilds. In permaculture, guilds are defined as webs of mutually beneficial connections between species, usually organized around one or two significant species. In general, these webs will include nutrient accumulators, such as nitrogen fixers. They will include insectary species. Fungi, bacteria and other microorganisms serve as nutrient translators. Animals garden the system, turning the earth, pruning, planting, fertilizing. The focus of this article is a particular guild: piñon-juniper and its associated species.

Piñon-juniper forests in northern New Mexico are frequently impoverished landscapes, susceptible to erosion and with a minimum of understory species. I suspect that this is a result of larger historical trends in the region. Many of these forests are a recent successional stage, having followed logging and sheep grazing, two highly destabilizing influences in the desert southwest. The junipers, followed by the pines, have colonized eroded and eroding sites and are in some instances the only vegetative cover serving to prevent further soil loss. I believe that the piñon and juniper have been incorrectly blamed for a process of desertification caused primarily by human activity.

A number of healthy situations can still be found in northern New Mexico, particularly in favored or inaccessible sites. Near the perimeter of the Sol y Sombra property is a striking example. A large juniper (*Juniperus monosperma*) grows in a small basin, fed by a drainage of several square yards. Growing up through its branches, on the north side where they are usually found, is a sapling piñon (*Pinus edulis*) of perhaps twelve feet. In the shade of these trees grows Poa fendleri, prickly pear (*Opuntia phaecantha*), cholla (*Opuntia imbricata*), wolfberry (*Lycium pallidum*), mullein (*Verbascum thapsus*), Erigeron, Artemisia, and lamb's quarters (*Chenepodium berlandieri*). At the edges of this grouping can be found chamisa or rabbitbrush (*Chrysothamnus nauseosus*), Apache plume (*Fallugia paradoxa*), sideoats grama (*Bouteloua curtipendula*), purple aster (*Machaeranthera bigelovii*), and other herbaceous species. Mistletoe sprouts from many of the juniper's limbs, and lichen can be found on the bark of its main trunk.

Evidence of animal activity is plentiful. Ant hills and gopher burrows appear under or at the edge of the trees. Bird droppings add fertility to the soil. Bees visit the flowering species. Towhees spread the mistletoe seeds and jays and squirrels visit the piñon. Rabbit droppings are plentiful, and occasionally we find scat of an animal who has been eating the rabbits. Beetles and other insects are common.

This coming together of plant and animal life results in a rich black layer of duff, shot through with fungal mycelia. In the wet months, mushroom fruiting bodies appear. A carpet of

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organic material holds moisture, recycles nutrients, and resists erosion. It is continually enriched by a rain of dust and pollen, bits of plant material, and animal and insect feces and bodies.

For all that the Sol y Sombra guild that I have just described stands out in comparison to the barren landscape common around Santa Fe, it is not all that rare. I have seen many such guilds, some of them far richer. A range of species that occur in similar circumstances are not yet found under this particular tree, so we will probably introduce them. These include wax and golden currants (*Ribes cereum* and *R. aureum*), silver lupine (*Lupinus argenteus*), Gambel's oak (*Quercus gambellii*), mountain mahogany (Cercocarpus montanus), banana yucca (*Yucca baccata*), wild four o'clock (*Mirabilis multiflora*), blue gilia (*Gilia longiflora*), scarlet bugler (*Penstemon barbatus*), claret cup (*Echinocereus triglochidiatus*), etc. Contrary to conventional wisdom, my experience is that piñon-juniper woodlands, if given the opportunity to recover, are diverse and rich in species.

Functional guilds are characterized more by diverse connections between species than by the numbers of species themselves. Gophers till the soil, creating ideal sites, for establishment of seedlings. The juniper is the nurse for many of these species, providing a toehold against wind and water erosion, suitable soils, and protection from browsing. Towhees introduce mistletoe into the maturing juniper, helping to pave the way for its eventual succession. The juniper and other woody plants provide food, scaffolding, and nesting sites for a variety of animals. All of the plant species serve to create microclimates, and gradually shift the type and variety of microclimates available. Animals serve as mobile components of the guild, planting, fertilizing, dispersing, and extending the edge of the forest.

A number of species found in this guild are nitrogen fixers, including mountain mahogany, apache plume, New Mexico locust, *Ceanothus fendleri, Amorpha canescens*, and silver lupine. This is common in desert climates, where nutrients are scarce. Nitrogen fixers introduce this important element into the whole system, where it is cycled by microorganisms, plants, and animals.

Fungi and bacteria break down organic material and serve as translators, providing nutrients in assimilable form to the plant communities and soil fauna which in turn translate nutrients into assimilable form for other animals. Rodents eat the fruiting bodies of fungus, combining spores with sugars from plants and depositing them in favorable locations in the form of neatly packaged "nutrient bundles." Predators may also assist in distributing fungal spores by harvesting rodents and converting them into even larger nutrient bundles. In this way, animals are not only responsible for distribution and planting of seeds, but also for the distribution of fungi and nutrients essential for healthy soil communities.

Bill Isaacs, a Santa Fe mycologist and native plant expert, has observed a specific relationship between cottontail rabbits and false truffles (Rhizopogon sp.). The rabbits eat the fruits of the fungus, breaking spore dormancy as they pass through the intestinal tract. The mycelium of the false truffles interact with the root hairs of the piñon, enhancing mineral absorption. The trees provide cover for the rabbits. The rabbits eat grass, creating opportunities for tree establishment, thus extending the forest. Where they eat, they defecate, spreading activated fungal spores to improve soil habitat for the piñon.

In places where guild systems exist, a healthy diversity of plant and animal species will be found. Soils are high in organic content and productive. Total biomass is high, particularly since guilds based on woody species are layered, using available space optimally. Nutrient cycling is effective due to concentration of species, habitats, and niches. Guilds are designed to make the best use of available flows of nutrients and energies in the landscape. They represent an evolutionary strategy of cooperation among species.

Many of the plants associated with piñon-juniper guild are edible and have been harvested by people for millennia. Pine nuts and acorns are high protein perennial crops. Currants, wolfberries, yucca, oregon grape, wild grape, and juniper all produce edible fruits. Wolfberries are often used by archaeologists as indicator plants for finding ancient settlements. Other plants are harvested as potherbs. Many have medicinal uses. This prevalence of useful species may indicate human intervention in the ecosystem in selecting for preferred plants.

The usefulness of wild species points the way to possible sustainable commercial yields from the piñon-juniper forest. Currently, piñon is cut and sold for firewood and the remaining grass grazed by cattle at very low rates of stocking. This is a low use of the energy, genetic resource, and biomass represented by such a system. Many of the species represented in this guild have a potentially higher value per acre than any of the uses (except perhaps real estate development) to which this ecosystem is currently put. Pine nuts were once an important cash crop in New Mexico. Acorn flour is delicious, highly nutritious, and only requires appropriate packaging and marketing to establish new commercial opportunities. Wild four o'clock is a highly valued medicinal herb for which demand continually outstrips supply. Wild fruits are enjoyed by connoisseurs and command high prices in gourmet markets and restaurants.

Healthy piñon-juniper woodlands are aesthetically appealing and form the basis for a growing demand for native plants. The market for seeds and live plant material continues to outstrip the ability of growers to supply. A single major highway revegetation project can eliminate all available sources of some native species for a year or more, and more and more landscape architects are including natives in their specifications. Sometimes the single most valuable harvest of a landscape is its seed resources.

These uses of the products of a piñon-juniper ecosystem are consistent with the concept of sustainable yield. Products can be harvested without damaging the living guild. In fact, if these products are demonstrably important commercial crops, they could form the basis for broadscale investment in stabilizing and revitalizing this ecosystem. Nor do they necessarily preclude careful extraction of firewood, grazing, and other harvests, so

long as such management supports and furthers the health of the ecosystem. Priority needs to be placed on the intrinsic value of natural systems, rather than on their exploitation for economic ends. If we are to realize a healthy land-based economy, we must do so by doing it smarter--by diversifying and spreading the risk of crop failure over a multiplicity of potential yields. This way of life was familiar to our ancestors. Our failure to pay attention to basic principles of natural systems when designing our economic strategies has resulted in widespread ecological deterioration. I propose that in the case of the piñon-juniper woodlands, understanding underlying guild structure and working to enhance and benefit from it provides one possible approach to sustainability.

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Bureau of Indian Affairs Pilot Woodlands Management Program

Beverly A. Schwab[1]

Abstract —The B.I.A. is in the fourth year of a pilot woodlands management program. Indian reservations in the Southwest have over seven million acres of woodland forest. Yet, historically, the primary use of woodlands has been for personal use fuelwood and piñon nut gathering. Until recently, the B.I.A./Tribes have received no funding for woodlands management. The purpose of the pilot woodlands management program is to:

1) Explore the feasibility of tribal economic development through management and utilization of woodland resources.
2) Study the potential for resource enhancement through woodland management.

This paper will summarize the activities of the B.I.A. Albuquerque Area pilot woodlands management program.

INTRODUCTION

Native Americans have utilized piñon-juniper woodlands for thousands of years. Many tribes favored P-J woodlands for winter home sites due to the mild winter climate. A wide variety of woodland products were used by these early Indians. Piñon nuts were sometimes the principle winter food, and years with poor nut crops were often disastrous. Woodland trees were also used for fuelwood, and for end products such as poles, roof beams, and handtools. The pitch was used to: make glue for jewelry making, waterproof basket waterjugs, make dye for blankets and wool, coat stone griddles, and for various medicinal purposes (Bureau of Indian Affairs 1988) (Lanner 1981).

Piñon-juniper woodlands are still an important resource for native Americans. Wood remains the principle source of heating and cooking fuel on reservations in the southwest. Piñon nut harvesting is also a good source of extra income. Livestock grazing is another major use. Piñon-juniper woodlands provide habitat for several big game animals and many birds, as well as small mammals. The economic value of woodland products on Indian reservations in the southwest is estimated to exceed $29,000,000 annually (Bureau of Indian Affairs 1988).

Despite the historical and current use of woodlands by native Americans, management of this resource has been minimal. Due to limited forest management funding, timber management has received higher priority on most reservations. Because of low volumes and slow growth rates, woodlands were thought to have little value as a commercial resource. However, in 1987, the Southern Pueblos Governor's Council made a formal request to the Assistant Secretary, Indian Affairs, for funding to inventory and begin management of woodland resource on reservations in the southwest. Because of this request, a study to evaluate woodland resource values and management needs on Indian lands was commissioned. The study report was produced in 1988. Due to the findings of this report, special woodlands management funding was appropriated by congress for the first time in 1989 for the B.I.A, and has continued for the last four years on a year-to-year basis. It is intended for the woodlands management program to go through a "pilot" stage, so that the feasibility and benefits of woodlands management can be assessed after a given period.

B.I.A. ALBUQUERQUE AREA WOODLAND MANAGEMENT PROGRAM

In the past four years, seven tribes within the Albuquerque Area have been funded for woodlands management pilot projects. Most of these tribes have a very limited timber

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resource, yet own thousands of acres of woodlands. Many of these reservations are also in remote areas where jobs are scarce. Woodland management funding has created opportunities for tribes to develop new sources of income from their forest resource.

Economic Development

Economic development is a top priority for these pilot woodland management projects. Unless the projects can prove that woodlands management is economically feasible, the program is doomed to failure. Consequently, a large proportion of the project funding has gone directly to the tribes to provide start up capital for woodland product enterprises. A total of six tribal fuelwood yards have been established. Most tribes have opted to test this type of enterprise because of its low overhead and simplicity of administration and operation. After three years of operation, several of the tribes involved are now looking into opportunities for expanding their enterprises to market a variety of products such as: juniper chip filled dog beds and scent bags, juniper furniture, bundled fuelwood, and piñon nuts.

The program is still in its infancy, and tribes are learning from their successes and failures. However, even though tribes are still in the learning process, over $200,000 in tribal employment and income have been generated from the projects to date. As tribes become more knowledgeable about product markets and funding opportunities, the potential for significant economic development is enormous.

Resource Enhancement

The remainder of the funding has been used by the B.I.A. to prepare and administer woodland management areas. Management objectives of the treatment areas has been diverse. Wood production is only one of the many reasons why management is desirable. Woodland management also offers the opportunity to improve wildlife habitat, increase forage for livestock, reduce soil erosion, control insect and disease problems, improve forest health and vigor, and increase piñon nut production. To learn more about woodlands management, specifically, response to treatment, the Bureau is in the process of installing long-term uneven-aged stocking studies on four reservations (Figure 1). Data from these studies will enable foresters to assess the response of woodland forests to treatment, and to determine which stocking levels are optimum for a variety of management objectives. An informational summary of the stocking studies can be found in Table 1.

Piñon nuts are the woodland product thought to have the most potential commercial value. In order to study treatment effects on piñon nut production, the Bureau is cooperating with the U.S.F.S. Rocky Mountain Range and Experiment Station in a series of nut production studies. The study plots are located

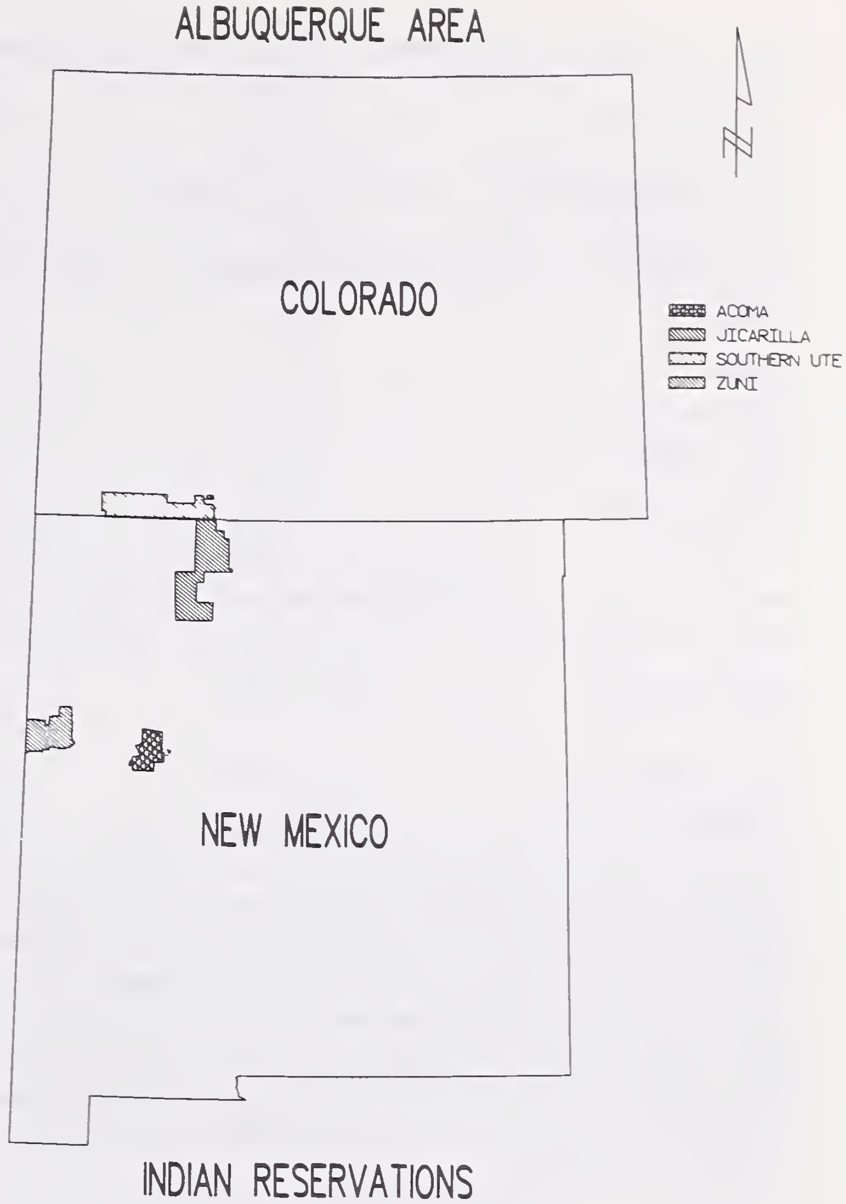

Figure 1. — Location of four long-term uneven-aged stocking studies by the B.I.A.

adjacent to the uneven-aged stocking studies. They consist of a one acre plot where all trees except for the best cone producers are harvested. The number of cones are counted on each tree within the plot and on number of sample trees within each of the stocking study plots. The main objective of the study is to determine the effects of stand density on nut production.

Some more informal types of studies are also being installed on several reservations in the form of silvicultural demonstration areas and photo point documentation. Silvicultural demonstration areas are blocks of different treatments laid out adjacent to one another within a woodland stand. Demonstration areas are valuable tools for foresters and tribal members alike. They allow foresters to monitor the response of a stand to a variety of treatments in order to learn which types of treatments are best for specific management objectives. They are also important tools for tribal members. When making management decisions, tribes can visit demonstration areas to actually see what various treatments look like. Oftentimes, foresters try to orally describe treatments to tribal members in the planning process. But the end result is often not what the tribe imagined. Demonstration areas take a lot of the guesswork out of the process.

Table 1. — Informational Summary of B.I.A. Uneven-Aged Stocking Studies.

	Jicarilla	So. Ute	Acoma	Zuni
No. of 2.4 ac Plots	4 + Control	3 + Control	3 + Control	3 + Control
Plot Densities (BA)	25,40,55,70,C	30,50,70,C	20,40,60,C	20,40,60,C
Nut Prod. Study	Planned '93	Planned '93	Planned '93	Installed '92
Habitat Type	PIED/QUGA	PIED/CEMO	PIED/FEAR	PIED/ARTR
Elevation	7300'	6700'	8000'	7100'
Aspect	SE	NW	Flat	Flat
Legal Description	T27N, R2W, Sec. 29, 30	T33N, R9W, Sec. 32, 33	T11N, R8W, Sec. 19	T10N, R18W, Sec. 9
Precip. Pattern	Winter	Winter	Summer	Winter
Soil Pits/Analysis	Yes	No	No	No
Soil Survey	Typed	Typed	Typed	Typed
Range	None to Date	Inventory '92	Inventory '92	Inventory '92
Down Wdy Fuels Inv	Planned '93	Planned '93	Planned '93	Planned '93
Wildlife Surveys	None to Date	Big Game '92	Big Game '92	Big Game, Small Mammals, Songbirds '92
Crown Cover Survey	Planned '93	Planned '93	Planned '93	Planned '93
Regeneration Survey	Completed '92	Planned '93	Planned '93	Planned '93

Photo point documentation is an inexpensive and impressive form of treatment monitoring. Photo point documentation consists simply of taking a series of photos of a treatment from the same point over time. Treatment effects, even in the short term, are often striking and might not be observed without photo documentation. Photo point documentation is done on all the stocking studies and on some of the demonstration areas and operational treatments.

CONCLUSION

Woodland management on Indian reservations within the Albuquerque Area is a new but growing program. The economic potential of woodland management is being explored through development of tribal woodland product enterprises. Ecologically based management activities are being implemented and monitored in order to learn more about treatment effects and benefits. Data collected from formal and informal treatment studies will provide valuable information for future management.

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Soil Nutrient Research on the Heber Ranger District Apache-Sitgreaves National Forest

Hazel Perry[1]

Abstract — Soil temperatures and vegetative and soil nutrients were measured during a prescribed fire study in fuelwood harvested piñon-juniper. Soil temperatures in the top 0-5cm reached 339°C under slash >25MT/ha. Vegetative nitrogen and phosphorus decreased as much as 91% due primarily to volatilization and erosion. Soil nutrient levels increased or remained unchanged.

Scientists from the Rocky Mountain Station are conducting several studies involving two sites on the Heber Ranger District, Sitgreaves National Forest, Arizona. This discussion emphasizes the soils aspect of these studies.

The Ancient Tank study is in an area dominated by *Juniperus monosperma* (one-seed juniper) with little interspace vegetation. The interspace vegetation is mostly annual forbs with some *Bouteloua gracilis* (blue grama). Soils are Typic Haplustalfs (Nelson 1992) derived from limestone interbedded with sandstone. In many areas, the soil is shallow and armored.

In an effort to increase forage, the district used fuelwood harvesting to remove trees greater than 7.5 cm in basal diameter from areas averaging 80 ha in size. They wanted to use commercial harvesters instead of opening the areas up to personal use cuts because the commercial cutters could be controlled under contract to complete clean harvests over a set time period. The problem incurred at the Ancient Tank site was that most of the sale areas they wanted to cut produced less than 6 cords/ha and the cutters felt they could not make money with the amount of time it would take to get a truck load of wood. So, the district paid harvesters an average of $40/ha depending upon the amount of wood they could get off the area (Mortensen 1991). The more wood the cutter could get to sell, the less the district had to pay.

Harvesting was completed on four areas over a 4 year period resulting in different age classes of slash. When we started the study, these sites were 1 year, 2 years, 3 years, and 4 years post-harvest. Harvesting resulted in an average of 45MT/ha of slash which we determined using methodology outlined by Brown (1974) in the Handbook for Inventorying Downed Woody Fuel which we modified for use in piñon-juniper.

The District was looking for information on the effects of burning slash on soil productivity. The Range Conservationist specifically wanted to know if slash age should be considered if they did decide to burn. To try and answer the District's questions as well as some on soil phosphorus and the long-term effects of fire, we selected four 1/2-ha blocks in each age class — three were to be burned with one left as a control. Within each block, we installed three 20 m transects for collection of soil, litter, ash, and slash samples.

The specific objectives were to measure soil temperatures associated with a prescribed piñon-juniper slash burn (Perry et al, in review), and to determine the long-term effects of prescribed fire on nutrient cycling under varying age classes of slash and at different soil depths.

Soil temperatures were measured by Steve Sackett and Sally Haase of the Riverside Forest Fire Laboratory using stainless steel thermocouples (Sackett and Haase 1992). Thermocouples were inserted horizontally within the top 10 cm of the soil at nine random locations in each block under heavy fuel (which we categorized for this area as greater than 25MT/ha), light fuel (less than 25MT/ha), and in the interspace adjacent to the slash. The thermocouples are attached by cable to data loggers which are housed in insulated aluminum boxes. Because of time and equipment restraints, we were only able to instrument two sites. We chose the one with the lowest slash load at 41MT/ha which was the 4-year-old site and the site with the heaviest fuel, the 2-year-old site with 51MT/ha.

In November 1989, 12 blocks were burned leaving only piles of white ash and burned stumps. To reach our objective of determining effects of fire on nutrients, we collected soil at 0-1, 1-2, and 2-5 cm depths along each transect immediately before and after the burn and again 4 months later in the spring of 1990.

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Soil samples were collected in all four age classes but due to budget constraints, only the materials from the 2 year and 4 year sites were analyzed. Materials from the 1 year and 3 year sites are in storage for later analyses. The soil was analyzed for seven different phosphorus fractions, organic carbon, exchangeable and total calcium and magnesium as well as total nitrogen, particle size, and bulk density.

Samples of litter and slash were collected immediately before the fire and ash was collect following the burn. We attempted to collect ash the following spring but there had been so much movement and mixing of soil and ash by wind that we were unable to collect a clean ash sample. Determinations made on these samples were oven dry weight, total phosphorus, calcium, magnesium, and nitrogen.

Figure 1 illustrates the maximum temperatures we recorded under heavy slash in the top 5 cm of soil. The highest temperature recorded at the 2 year site was 95 °C and the mean was 70 °C. On the 4 year site, the highest temperature recorded was 339 °C and the mean of all nine locations was 203 °C. Figure 2 illustrates longer temperature durations on the 4-year-old site where temperatures remained over 100 °C for more than 14 hours and return to near ambient at approximately 35 hours after ignition. The measured temperatures never exceeded 100 °C on the 2 year site and returned to near ambient within 10 hours. I say 'near' ambient because the fire causes a darkening of the surface and removal of shade producing slash so the ambient temperatures on these sites will be higher following the fire.

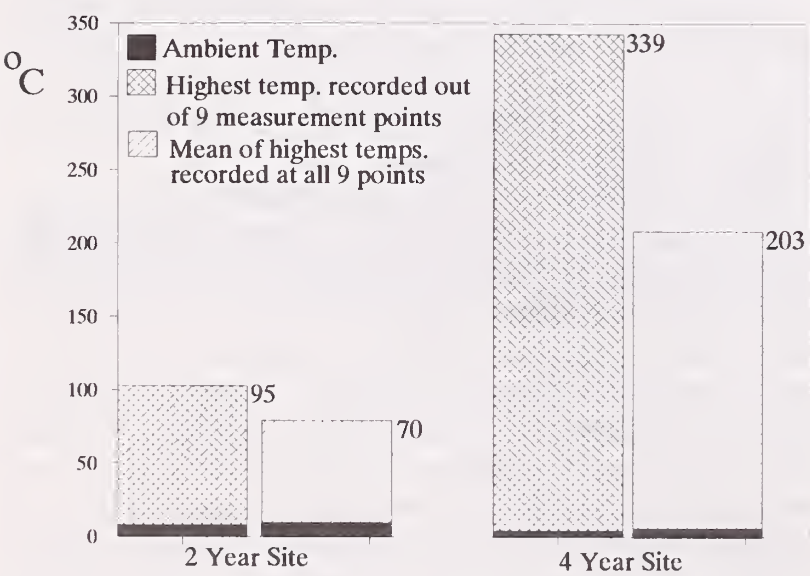

Figure 1. — Soil temperatures associated with a piñon-juniper slash burn in central Arizona.

Slash weights reported for these areas were 51MT/ha on the 2 year site and 41MT/ha on the 4 year site. Why then do we see this difference in soil temperatures? It could be the result to two things. First, the litter layer on the 4 year site (Figure 2) was heavier and denser with an average weight of 29MT/ha and depth of 0.5 cm. Whereas, the 2 year site had 18MT/ha litter at an average depth of 1.8 cm. The extra 2 years slash was on the ground on the 4 year site allowed for greater litter accumulation and compaction. Secondly, slash on the 4 year site appeared to have accumulated heavier materials nearer the soil surface due primarily to weathering and gravity. This accumulation of surface fuel resulted in higher, longer duration soil temperatures. Figure 3 also illustrates the loss of vegetative material on a weight basis. On the 2 year site, there was an 86% decrease in vegetative material from slash and litter to ash and a 52% decrease on the 4 year site. These losses are attributed primarily to wind during and immediately following the fire which carried large amounts of ash off site. As mentioned earlier, four months after the fire wind had moved enough soil and ash to make collection of ash samples impossible. Malchus Baker, a Research Hydrologist at the Rocky Mountain Station in Flagstaff, is currently studying wind erosion on burned and crushed sites on the Heber District.

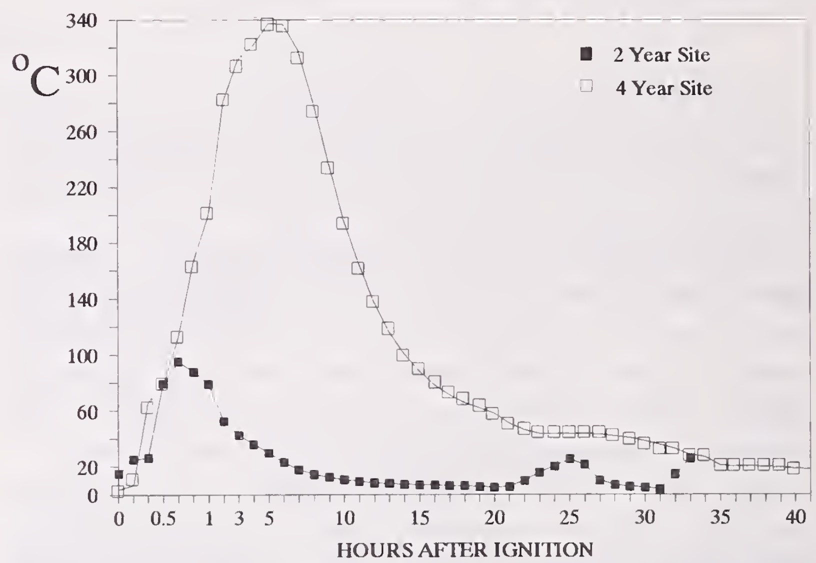

Figure 2. — Soil temperature durations in the 0-5 cm soil depth on a piñon-juniper slash burn in central AS.

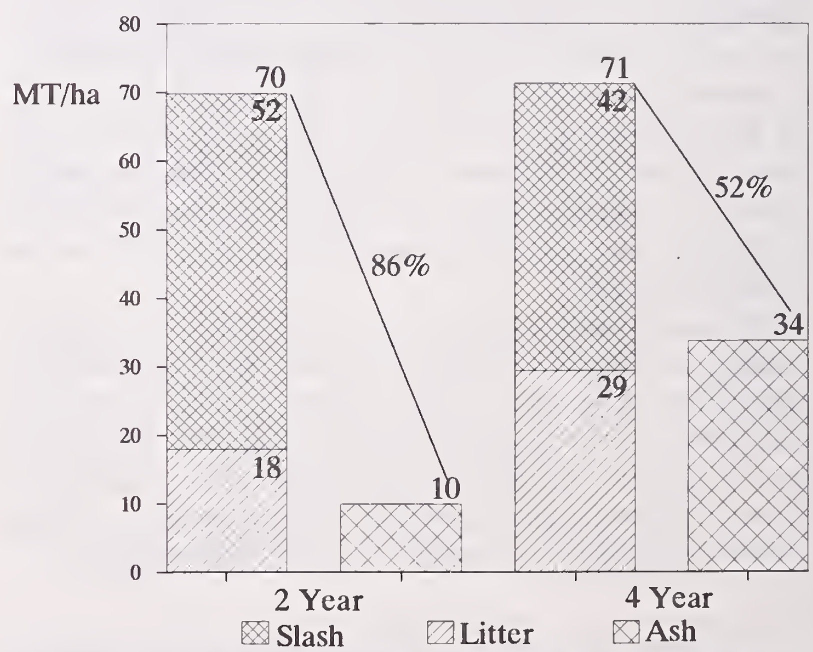

Figure 3. — Vegetative material weights on a piñon-juniper slash burn in central Arizona.

Nutrient determinations (Table 1) illustrate a decrease in nitrogen and phosphorus from that contained in the slash and litter to what remained in the ash. This decrease is due primarily to volatilization and erosional losses. On the 2 year site, we had a 91% decrease in both phosphorus and nitrogen. On the 4 year site, which had somewhat less erosional ash loss, we found an 88% decrease in phosphorus and 72% decrease in nitrogen.

Table 1. — Changes in vegetative nitrogen and phosphorus (kg/ha) following a prescribed piñon-juniper slash burn in central Arizona.

	2 Year Site		4 Year Site	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Pre-Burn (Litter+Slash)	290.5	34.8	312.2	31.1
Post-Burn (Ash)	25.8	3.0	87.7	10.1
% Decrease	91.1	91.4	71.9	67.5

One year following the fire, there was no vegetation in the burned area and 3 1/2 years following the burn there were only a few annual forbs in the burned areas with grass cover right up to the edge of the burn.

Table 2 lists soil nutrient changes for the top 5 cm of soil. We found increases in total nitrogen, available phosphorus, and exchangeable calcium and magnesium. We found no decreases in soil nutrients. It is well documented that there is a release of nutrients following fire due to oxidation of organic materials once held in the vegetative materials (Isaac and Hopkins 1937, Smith 1970, Lewis 1974, Stark 1977, DeBano and Conrad 1978, Stednick et al. 1982, Wright and Bailey 1982, Giovanni et al. 1988). In this study, however, it's obvious when considering that there is little or no vegetation in the burned area that something else is happening in the soil. Could it be a destruction of soil flora and fauna (Hayward and Tissot 1936, Ahlgren and Ahlgren 1965, Wright and Bailey 1982)? Very probable. An alteration of nutrient ratios? Probable. Release of some unknown compounds from the resinous wood slash? Maybe. Hydrophobic condition of the soil? A test for hydrophobicity in this instance indicated no problems but hydrophobic soils have been known to occur following piñon-juniper fires. Could it be a lack of seed source to recolonize the burned areas? Possible in some of the 12 burned blocks, but not in all. Could it be a combination of conditions, some of which we can only guess at and some that have never occurred to us? This is the most likely scenario of all.

Answers to some of these questions were what we were hoping for with a long-term study until one fateful day 2 years ago when there was a miscommunication among some folks working out on the Ancient Tank Site. The District decided not to burn the remaining hectares of slash, based partly on our findings. They have a roller chopper that they pull behind a tractor to break up the slash and get it down into the soil surface. It can then decompose faster and provide an effective soil cover.

Table 2. — Changes in soil nutrient levels following prescribed piñon-juniper slash burning in central Arizona.

	2 Year Site	4 Year Site
Total nitrogen	No change	35% increase
Total phosphorus	No change	No change
Total calcium	No change	No change
Total magnesium	No change	No change
Available phosphorus	83% increase	93% increase
Exchangeable calcium	129% increase	170% increase
Exchangeable magnesium	No change	45% increase
Organic carbon	No change	No change
pH	No change	No change

The chopper also produces trenches that provide microclimate conducive to seedling establishment and appear to increase infiltration, although that hasn't been measured. The chopped areas are much more aesthetically pleasing than untreated or burned slash, and areas that were chopped only 1 year ago appear to have greater forage production and species diversity.

So, what was the problem on the burned sites? The tractor operator had been told to chop everything in the fuelwood harvested areas. "Everything?" he asks. "Yes, everything." By now you've probably guessed that even though there was no slash to chop on the burned blocks and the permanent transect markers were sticking up all over, he ran the chopper through the blocks churning up the soil on the transects and flattening the markers.

Well, things happen, and we gained some good information but we didn't accomplish any of our long-term goals. That brings us to the second study we're conducting on the Heber Ranger District.

The Mud Tank area has approximately 60% *Pinus edulis* (piñon pine) and 40% juniper species, primarily one-seed juniper but with some *Juniperus deppeana* (alligator bark juniper) on better sites. Soils are derived from limestone parent material interbedded with sandstone. The study is made up of 33 4-ha blocks over which four silvicultural treatments are being applied by commercial fuelwooding. In this case, there is enough fuelwood that the cutters pay the district to cut.

The silvicultural treatments are single-tree selection where tree densities are reduced approximately 50% while maintaining diameter distribution, overstory removal where everything greater than 18 cm basal diameter is cut, type conversion where all trees are cut, and no cutting. Soil nutrient work is being done in the overstory removal, type conversion, and no cut treatments. There are 10 4-ha blocks in each treatment and half of these will have prescribed slash burns.

Gerald Gottfried, Research Forester with the Rocky Mountain Station in Flagstaff, is studying effects of all four silvicultural treatments and prescribed fire on tree regeneration and growth. He is also working with Bill Kruse, Research Range Scientist

with the Rocky Mountain Station in Flagstaff, on understory/overstory production. Bill Kruse is also monitoring small mammal populations and is working with me on nutrient cycling in the soil/blue grama system throughout the growing season.

Specific soil nutrient objectives are to measure the soil temperatures associated with these different levels of fuelwood harvest and to once again attempt to determine long-term effects of fuelwood harvest and fire on nutrient cycling. The nutrient work has been expanded over what we were doing on the Ancient Tank study. Samples of soil and blue grama have been collected once every 2 weeks throughout the growing season for the past 3 summers. This sampling will continue for at least 5 years post-treatment. Soil, litter, and slash will be collected within a couple of days before burning and soil and ash will be collected as soon after burning as it is cool enough to work in the area and annually for at least 5 years post-treatment. We're currently getting our downed woody fuel measurements and will be measuring concentrations of nitrogen, phosphorus, calcium, magnesium, sodium, potassium, manganese, copper, and zinc in the slash, litter, and ash. The soils work has also been expanded to include ammonia and nitrate; exchangeable phosphorus, calcium, and magnesium; total nitrogen, phosphorus, calcium, magnesium, sodium, potassium, manganese, copper, and zinc; organic carbon; pH; and bulk density.

Because fuelwood harvest could not be completed in one year, ten of the blocks were harvested last year and will be burned in Fall 1993. The other twenty will be completed in May 1993 and will be burned in Fall 1994.

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The Piñon-Juniper Invasion: An Inevitable Disaster

Sid Goodloe[1]

An adequate water supply has become a major concern to our nation, especially in the western states. Watershed management is of vital importance to all of us, and all other singular resource uses must give way to holistic planning and action that affect those watersheds.

Most of the 23 million acres classified as piñon-juniper ecosystems in New Mexico influence our watersheds dramatically. Their deteriorated condition is beginning to contribute to significant conflicts. For example, water tables are declining, surface flow in the Pecos River is down 30% and the city of El Paso has taken legal action to obtain New Mexico water. In the future more conflicts will occur between states, cities, rural and urban areas, and the intermingled land ownership pattern throughout New Mexico and the west.

To reinforce what I said last year, I hope to make you aware of what I consider to be the most serious natural resource problem in the southwest. The invasion of our grasslands, savannas and woodlands by piñon, juniper, ponderosa, mesquite and sagebrush has reached a flash point. This condition is due to late 18th and early 19th century abuse by livestock, followed by 80 years of fire suppression. We must accept the responsibility for the deterioration of our water supply, soil stability, wildlife habitat, aesthetic values and wildfire control. We should consider immediate, drastic action to correct an impending disaster.

I am speaking to you now as a professional land manager and non-public land ranch owner. I live in the heart of the P-J ecosystem and have spent more than 35 years learning about and manipulating that ecosystem. I have been involved in land management in a dozen countries from the Australian outback to the great savannas of East Africa and all of the Southwestern states. I feel that I have had sufficient education and experience to understand what drives our P-J ecosystem and apply that knowledge in a holistic approach to land management. I am very fortunate in that I have been able to take action, and observe the results on my ranch over a long period of time. There have been mistakes as well as correct actions.

Before I share with you what I have learned, perhaps we should talk about the history of our watersheds and how we arrived at where we are today.

Watersheds in the Western states are generally harsh ecosystems. Typical rainfall averages between 8 and 20 inches, precipitation patterns are erratic and evaporation losses high, temperatures are often extreme, the topography rough, and the soils can be shallow and rocky. The New Mexico Environment Department reports that 95% of the states' surface water is impacted by nonpoint source pollution and that turbidity is one of the major causes of use impairment in these waters. Reports by early surveyors, naturalists and trappers detail the abundance of grass and clear, clean water found on these same watersheds, a sharp contrast to the conditions seen today.

The cause of Western watershed demise was put in perspective by E. O. Wooton in 1908 when he said, "The stockman could not protect the range from himself, because any improvement of his range was only an inducement for someone else to bring stock in upon it: so he put the extra stock on himself. As a result, native grasses were replaced by sagebrush, mesquite, juniper, piñon and other invading brush species that were less suited for holding soil in place and which were more efficient at water extraction. Topsoil washed away; gullies formed from unchecked, concentrated runoff; streambanks eroded and downcut; water tables lowered; and perennial streams became intermittent or dry.

The harshness of the environment, low precipitation, wind, high evaporation, etc. contributes to the difficulty in re-establishing the climax or the highest ecological condition of the watersheds. As a result, simple manipulation of a single factor such as reducing livestock numbers is not sufficient to result in significant environmental improvement. These systems will take hundreds of years to recover by themselves. Direct actions aimed at total watershed rehabilitation applied in a holistic manner are necessary to ensure the restoration of Western watersheds and associated natural resources.

I would like to share with you the positives and negatives that affect the actual implementation of actions taken to reverse the downward trend and head it back toward climax.

[1] *Rancher, Campitan, New Mexico.*

POSITIVES

1) Some people are beginning to look beyond the paradigm: "All trees are good and all fires are bad." The Smokey Bear Syndrome is beginning to break down.
2) The Forest Service has a new P-J ecosystem management strategy in Region III.
3) The Carrizo Project in the Lincoln National Forest has received substantial grant monies to produce a video that will alert the public and our Federal Land Managers as to the seriousness of watershed deterioration in the Southwest.
4) Prescribed burning is becoming an integral part of public and private land management. We have come full circle: From evolutionary dependency on burning, to resistance to fire, to acknowledging its importance to the natural ecosystem. Now we must learn how to make fire work for us under restrictions imposed by urban sprawl, recreation, summer homes, etc.

NEGATIVES

1) Mind Set: Most people think New Mexico should look exactly as it looks today. A vegetative history study being conducted by NMSU on the Pecos River watershed will prove that assumption to be untrue.
2) Appeals: Many are well intentioned, but based upon emotic without a complete understanding of the ecosystem in question.
3) Threatened and Endangered Species Act: The act is often misinterpreted by the public and the agencies responsible for its implementation and enforcement. On public land it has been misused in cases to pursue personal interests. Some species have been listed before through surveys have been made. The U.S. Fish and Wildlife service must balance T & E species values with watershed values and provide incentives for management favorable to T & E species.
4) Archaeological Evaluation: Watershed rehabilitation is severely curtailed in the P-J ecosystem when shards are discovered and a large area is designated as an archaeological site. No one is accountable or required to prove whether that area is an actual site or just a broken pot. This over protective policy will greatly inhibit watershed restoration.
5) CO_2 Research: Recent work by Dr. Idso of the ARS Water Conservation Lab in Phoenix, related to global climate change and vegetation dynamics, indicates that woody plants have an increased growth and competitive ability over warm season grasses. He has proven that an 85% increase in atmospheric CO_2 increased tree growth rate 3 times. He expects a growing invasion of grassland by shrubs and trees as the air's CO_2 content continues to increase.

I have noticed many contradictions at this symposium. We all want to do the right thing, but have very diverse opinions and conflicting information. Some examples:

1) One speaker says the piñon is returning to old sites, another says new areas are being invaded.
2) Some are concerned about eradication of the piñon, others about overpopulation.
3) Nut production could be decreased by fuelwood harvest. Your garden is planted and growing, get rid of the weeds by demanding that the invaders be cut first.
4) Some believe a solid or semi-solid canopy is preferred wildlife habitat--others a savanna.
5) Some say erosion rates are the same on treated and untreated P-J, others say treatment is mandatory to save resources and archaeological site.

Why can't our next symposium hammer out a consensus on these and other differences? Then take action. What happened to my challenge to Commissioner Baca?

I would like to suggest a new approach to P-J research:

1) Can we increase nut yields of existing stands of piñon by cultivation (removing invaders and other excess growth) or fertilization sludge?
2) Develop harvest methods that are economical but not detrimental to wildlife.
3) What are the benefits of fire? How do we manage it?
4) What is the best fuelwood harvest method?
5) What nutrients are recycled by fire? How do they benefit the ecosystem?
6) Are aquifers replenished more rapidly under grasslands or P-J woodlands?
7) How does increased CO_2 affect P-J growth and competitiveness.

Watershed management must be re-evaluated on both public and private land in the Southwest. Hopefully, you have listened with an open mind and will respond with your own analysis of this very serious situation.

Carrizo Demonstration Area: Restoration of a Southwest Forest Ecosystem

Richard S. Edwards[1]

Abstract — The Carrizo Demonstration Area is located on the Smokey Bear Ranger District, Lincoln National Forest. It encompasses 55,000 acres of National Forest and private land, and is comprised mainly of piñon-juniper forest. The Carrizo Demonstration Area was established in 1989 as a pilot project designed to restore and sustain watersheds, increase natural food production for wildlife and livestock, and increase biological diversity by managing the area based on ecological principles. The Carrizo program is a demonstration of the Forest Service's ecologically based, multiple resource management. The primary purpose is to provide stewardship of the land to achieve and sustain desired conditions, provide cooperative partnerships to plan and implement projects, and utilize research and technology to provide quality on-the-ground resource management and protection. Over 2,400 acres of multi-resource improvements have been planned and implemented thus far to begin a transformation of the area toward desired future condition. The desired future condition will be achieved when active accelerated soil erosion is stopped, steep gully slopes are stabilized, and permanent riparian vegetation is restored. A mosaic of vegetative structural age classes and densities will exist within the different ecotypes, moving toward a balanced and stable ecosystem. Enduring partnerships with landowners and permittees will be permanently established to aid in sustaining the desired condition of the land.

INTRODUCTION

The Southwestern Region is gearing up to implement a program that emphasizes an ecological approach to multiple-use management of the piñon-juniper ecosystem. The Lincoln National Forest started on a project about four years ago, called the Carrizo Demonstration Area. Much of the Carrizo area now contains large expanses of continuous canopy piñon-juniper forest. Under these present conditions, natural openings are dominated by young piñon (*Pinus edulis*) and juniper (*Juniperus monosperma*, *Juniperus deppeana*, and *Juniperus scopulorum*) trees, and historically open woodlands have become dense thickets. Due to the increased competition from trees, these ecosystems are devoid of the grasses and other vegetation that hold the soil in place, contribute to plant diversity, and provide food or cover for various wildlife and livestock. Much of the productive soil beneath these dense woodland stands has eroded away, leaving behind an extensive gully system which continues to transport silt-laden water into streams and rivers, and serves to lower the water table. The need for this project was brought about through the urging of area private landowners and grazing permittees, who for years have had to contend with the deposition of millions of tons of sediment that originated on National Forest land, as well as a steady decline livestock grazing capacity due to a decrease in forage.

The piñon-juniper woodlands have gone through many changes over the past 20,000 years. Due to gradual global warming, they have migrated from lower elevations to higher elevations and extended their range from southern latitudes to northern latitudes (Betancourt et al.1986). By the middle of the 19th century, most of the piñon-juniper woodlands in south-central New Mexico were located on steeper, rockier slopes, although transition zones existed between piñon-juniper and the short-grass rangelands and piñon-juniper and ponderosa pine (*Pinus ponderosa*). Much of the woodland area, in particular the lower elevation zone, was very open in appearance.

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It had been maintained in that condition by periodic fire. Tree ring studies in New Mexico indicate that many forests burned, on the average, at 7 to 10 year intervals (Stoddart et al. 1975) prior to settlement of the area.

But one of the most remarkable changes occurred during the last 100 years. During the late 1800's and early 1900's, much of New Mexico received intense grazing pressure from domestic livestock. Lincoln National Forest records show that by 1902 on what is now the Smokey Bear Ranger District, 80,000 head of livestock were grazing on the Lincoln Forest Reserve (Hightower, 1902). To put this in perspective, today the permitted livestock - the grazing capacity is 5,000 head of livestock. Because of this heavy livestock grazing, the grasses were reduced to the point where they could no longer carry these periodic wildfires which kept the piñon and juniper trees in check. The reduction in available fuels in combination with fire suppression by public land management agencies, led to a proliferation of young piñon and juniper trees that throughout this century have increased, and are out-competing native grasses and forbs. As tree canopies became closed, grasses and plants that prevented erosion and provided forage for wildlife and livestock rapidly declined because they could not compete with the piñon and juniper trees (Evans, et al. 1988). Many of the perennial streams and springs, life-blood for the rich diversity of riparian and wetland ecosystems, were in part lost because of the excessive water requirements of these woodland trees (Ponce and Lindquist, 1990).

Livestock producers throughout the Southwest have for many years been concerned because of the long-term loss of forage productivity associated with this situation. Deer, elk, wild turkey, many songbirds, and other species of wildlife have been adversely affected by this change in habitat conditions. Private landowners adjacent to the National Forest have had to contend with the deposition of millions of tons of sediment that originated on the forest. Water, a scarce and precious commodity throughout the southwest, requires healthy forest watersheds. The quality, and potentially the quantity of water supplies for nearby communities, agricultural centers in Pecos River Valley and Tularosa Basin, and local wildlife and livestock are affected by the condition of the watershed.

MISSION

Our mission for the Carrizo area is to establish cooperative partnerships to aid in the development of sound land stewardship principles and to serve as examples in the implementation of land management activities to restore watersheds to satisfactory condition. Stewardship goals also include providing for a variety of wildlife habitats, increasing plant and animal diversity, restoring the natural beauty of the landscape, and improving overall ecosystem health. Management strategies focus on soil stabilization practices, vegetation management, water resource development, vehicular travel management, and sound range management practices, and are based on the best scientific and management information available.

The desired future condition will be achieved when active accelerated soil erosion is stopped, steep gully slopes are stabilized, and permanent riparian vegetation is restored. A mosaic of vegetative structural age classes and densities will exist within the different ecotypes, moving toward the balance and stability which occurred prior to European man's settlement of the area. Prescribed fire will be introduced to resemble the natural fire frequency that evolved with, and shaped the natural ecosystem. Enduring partnerships with adjacent landowners, traditional and non-traditional users, and nearby communities will be permanently established to aid in sustaining the desired condition of the land.

ECOLOGICAL APPROACH

The focus in the development of the Carrizo project was the recognition that all resources are interrelated and the integration of all resources into a management system is essential for long term success. Each aspect of the project was evaluated for it's effects on all resources, including the human environment. Our past custodial management philosophy for piñon-juniper ecosystems has led to a steady decrease of resource values (Doughty, 1987). The Carrizo area interdisciplinary planning team devised strategies to restore and sustain woodland watersheds. The major identified elements of this program are watershed, wildlife, vegetation, ecology, and range management. Through the use of the Southwestern Region's Terrestrial Ecosystem Survey the team identified high priority potential treatment areas as those with unsatisfactory watershed condition and high soil productivity. With the help of cooperative partnerships, treatments to produce desired conditions have included rehabilitating gullies by constructing small dams and reshaping gullies; establishing native vegetation to stabilize the soil by thinning trees for fuelwood, removing unwanted trees excess trees through mechanical means, prescribed fire, and by reseeding disturbed areas; providing dependable water supplies for wildlife by restoring and protecting riparian areas, installing inverted umbrella trick tanks, and developing existing springs; increasing overall forest health through harvest of trees in diseased or overstocked timber stands and through prescribed fire; and establishing travel access in line with resource needs by closing or obliterating unnecessary roads, relocating roads to more stable or suitable areas, and maintaining necessary roads and trails.

STEWARDSHIP

The restoration of watersheds is designed to stop excessive downstream sedimentation, preserve soil productivity and increase the duration of channel flows. In addition to stabilizing watersheds, benefits of the ecosystem approach being implemented include increased wildlife habitat capability, improved rangeland condition, increased visual diversity, and an increase in supply of forest products such as fuelwood, fence posts, vigas and poles. Once ecological restoration is established, the emphasis will be on sustaining a healthy ecosystem. Sound

range management practices, such as deferred rotation grazing, fuelwood harvest, and the use of prescribed fire to maintain diversity, will be used to achieve a sustainable ecosystem. Where treatments have been implemented, watershed conditions have improved dramatically. Cool season native species of grass and forbs which were once thought to be lost have returned in abundance. In several drainages, springs have begun to flow again, creating many opportunities to establish or enhance riparian vegetation. As a result of these changes, many species of wildlife which were declining in numbers have returned to the area. A more diverse setting across the landscape has increased the scenic quality of the area, and will allow future resource management to more easily maintain a natural appearance.

Positive changes have even begun to occur on adjacent private land following treatments accomplished on National Forest. In one area, a pond located on private land had filled with sediment from past gully and sheet erosion transported by overland flow from the National Forest. The landowner removed 4,800 cubic yards of topsoil from this pond at the same time watershed restoration treatments were being implemented above the pond on the National Forest at the same time watershed restoration and vegetation treatments were being implemented above the pond on the National Forest. During Spring season, a spring which had not run in at least 35 years began to flow. The large spring, as well as many other new, but smaller springs in adjacent drainages, continued to flow throughout the summer, filling the pond with clean, clear water. In addition to baseflow increases, sediment coming from the National Forest was minimal. The landowner was able to stock the pond with trout and catfish, and is now the permanent summer residence for many waterfowl.

Opportunities to improve economies within the surrounding rural communities have been enhanced due to increased production of forest products such as fuelwood and poles for vigas, and an increase in big game wildlife. Partnerships with adjacent landowners and others have opened up new lines of communication and have substantially increased the level of trust with our public.

PARTNERSHIPS WITH PEOPLE

Partnerships are an integral part of this effort. Thirteen grazing permittees, three adjacent private landowners, New Mexico Department of Game and Fish, New Mexico Division of Forestry and Resource Conservation, New Mexico State University (NMSU), New Mexico Range Improvement Task Force, and NMSU Cooperative Extension Service participated in long range project development. Numerous field trips involving diverse groups of constituents have been hosted to inform the public of the need for a stewardship approach to management of the piñon-juniper ecosystem. Congressional representatives have been closely involved throughout both the planning and initial implementation phases of the project.

Grazing permittees and private landowners have been the primary partners with the Forest Service for site specific watershed restoration and vegetation management projects. Project implementation partnerships are designed to meet multi-resource objectives by achieving complete treatments. For example, commercial fuelwood cutters have historically harvested only those trees which can be sold for firewood, leaving hundreds of excess trees per acre. Commercial fuelwood cutters within the Carrizo area now cut all trees not designated to be left. In fact, some partners can harvest a fuelwood area by written prescription, no longer needing the Forest Service to designated leave trees, creating additional savings to the government. Private landowners have purchased fuelwood sales on the national forest, and perform the same treatment on their adjacent private land. One landowner even entered into a cooperative agreement where vegetation on both National Forest and private land was managed with a prescribed burn.

COLLABORATION WITH RESEARCH

An ongoing focus of the Carrizo project has been to attract interest from researchers to explore the many questions associated with managing piñon-juniper woodlands on a landscape scale. Many institutions, organizations and individuals are involved in ongoing piñon-juniper research. The Rocky Mountain Forest and Range Experiment Station is currently researching on-site soil productivity and modeling soil erosion the Carrizo area. Other efforts include Southwestern Region's New Mexico Piñon-Juniper management initiative, U.S. Department of Agriculture's cooperative Pecos River Basin Study, NMSU Cooperative Extension Service's rangeland watershed program, and New Mexico Department of Game and Fish - Habitat Improvement Stamp (Sikes Act) program.

PROJECT REVIEW

Since the inception of the Carrizo Demonstration Area in 1989, a number of projects have been implemented which are moving the area closer to the desired condition. With the help of cooperative partnerships, approximately 1,550 acres of unsatisfactory condition watershed have been treated through vegetation management to increase herbaceous ground cover, 3.4 miles of gullies have been treated through installation of structural improvements or gully sideslope stabilization, and four miles of roads have been obliterated to reduce another source of downstream sedimentation. Specific improvements for wildlife habitat have been implemented on almost 900 acres through prescribed fire or creation of wildlife openings. In addition, two wildlife water developments were installed, and 15 acres of existing riparian have been fenced to exclude cattle grazing. Forest products sold as a result of vegetation treatments include 2,850 cords of fuelwood, 4,000 board feet of timber, and 500 small and medium poles.

Implementation of another project is underway to improve habitat for big game wildlife, as well as northern goshawk, using prescribed fire. Except under extreme conditions, use of prescribed fire to create openings within most areas of piñon-juniper is very difficult to accomplish successfully. This project was designed to thin seedlings and saplings prior to burning to create the necessary ground fuels to carry the fire. The fire will then result in a natural appearing mosaic of different habitat structural stages across the landscape. The natural food supply for big game wildlife as well as goshawk will be increased, and watershed conditions will be improved through increased ground cover.

CONCLUSION

The management situation in northern New Mexico is different than in south-central New Mexico, primarily from the cultural value standpoint and usage of piñon-juniper woodlands. But the ecological condition is essentially the same. Watersheds are being severely degraded to the point where site productivity is being lost. We cannot afford to lose much more topsoil from our woodland watersheds without seriously endangering production of commodities such as the piñon nut crop and fuelwood. As pointed out earlier, we have already experienced the loss of understory vegetation critical to wildlife and livestock. And possibly worst of all, damage to riparian areas has been extensive.

The ecological approach to multiple use management is a win-win proposition. Take piñon nut production for instance. I've seen enough this week to show me that if you thin some selected piñon-juniper sites, larger piñon trees could be grown, and thereby increase the production of piñon nuts. By lopping and scattering slash from the thinning, ground cover would be increased, reducing erosion. And as shown by projects implemented within the Carrizo area, diversity for all resources would be increased.

For Carrizo, one of our basic objectives is to test different treatments for managing woodland watersheds. Some of the treatments will not respond the way they are designed. But the point is, we have already learned a great deal from past mistakes and successes, and we will continue to monitor our projects to learn and make the necessary adjustments to achieve the desired future condition. The Southwestern Region of the Forest Service has already taken a major step forward in recognizing the values and complexities of the piñon-juniper ecosystem.

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Procedural Guidelines for Developing Soil and Water Conservation Practices in Piñon-Juniper Ecosystems

Charles L. Spann[1]

Abstract — "Approximately 3.5 million acres or about 35 percent of the piñon-juniper (P-J) woodland within the boundary of National Forest System lands in the Southwestern Region are considered to be in unsatisfactory soil and watershed condition." This condition has lead to a concern about the quality of water flowing from these lands. To address water quality concerns like this, where the pollution is diffuse (nonpoint pollution sources, [NPS]) the Forest Service in the Southwestern Region has developed a process outlined in "Soil and Water Conservation Practices Handbook." The process involves using known programmatic approaches to develop site specific practices. This is done in the framework of the Southwestern Region's Integrated Resource Management (IRM) process. In addition to the handbook, the Forest Service is continuing to develop accompanying documents such as the "Watershed Management Practices for Piñon-Juniper Ecosystems" a November 1992 guideline.

Soil and water conservation practices that provide favorable conditions of flow have been a long standing theme of the Forest Service. The 1897 Organic Administration Act, which basically created the Forest Service, states, "The Secretary of Agriculture shall make provisions for the protection... of the national forests... and he may make such rules and regulations and establish such service as will insure the objectives of such reservations, namely, to regulate their occupancy and use and to preserve the forests thereon from destruction..." This is the legal basis for regulating land uses on the National Forests. Gifford Pinchot, one of the first Chiefs of the Forest Service (1898-1910), developed the Use Book to guide the Forest Service in managing National Forest System lands. The Use Book in many places discusses conservation of soil and water, for example: "The Forests here are created and maintained... to prevent the water from running off suddenly in destruction floods." "The permeate wealth of a country comes form the soil. To insure permanent wealth the soil must be kept productive...," and "The forest cover is also very important in preventing erosion and the washing down of silt." As the Forest Service developed its practices through the years soil and water conservation has been one of its guiding principals. Today in the Southwestern Region the Forest Service has continued the Pinchot tradition of putting its guidelines in to handbook form. The "Soil and Water Conservation Practices Handbook" FSH 2509.22 and the "Watershed Management Practices in the Piñon-Juniper Ecosystems" are two good examples of this. The "Soil and Water Conservation Practices Handbook" (SWCPH) is part of the Forest Service's Directive System and can be modified as new approaches are developed. In its present form it outlines the use of soil and water conservation practices in the IRM process to develop Best Management Practices (BMP's) for protecting and enhancing water and soil quality. BMP's are defined as "A practice or a combination of practices, that is determined by a State (or designated area-wide planning agency, which the Forest Service has been designated by both New Mexico and Arizona) after problem assessment, examination of alternative practices and appropriate public participation to be the most effective, practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals." This is a definition found in the Clean Water Act. The Forest Service in the Southwestern Region extends this in the SWCPH to include protection and enhancement of both water and soil quality. The IRM process, which guides the development is broken into phases as follows:

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IRM Phases

- Scoping

1. Define Decision, Review Plans.
2. Develop Project Concept.
3. Conduct Extensive Reconnaissance.
4. Prepare Feasibility Report.

- Analysis

5. Link to Budget.
6. Conduct Intensive Reconnaissance.
7. Finalize, Compare Alternatives.
8. Select Preferred Alternative

- Documentation

9. Prepare Environmental/Decision Documents.

- Implementation

10. Check Process Record.
11. Prepare Project Action Plan.
12. Implement Project.

- Monitoring

13. Monitoring and Evaluate Results.

Following these phases meets the intent of the Clean Water Act in developing BMP's for preventing or reducing the amount of pollution generated by nonpoint sources. Most all of the activities that the Forest Service conducts in the piñon-juniper ecosystems are of a nonpoint nature and are related to soil movement into streams(sedimentation). Again, by using the programmatic soil and water conservation practices outline in the SWCPH and working them through IRM the Forest Service develops site specific practices for protecting and enhancing soil and water quality. The programmatic soil and water practices are broken down functionally as follows:

Resource Management Activities

- Pesticide Use Management and Coordination
- Range Management
- Recreation Management
- Timber Management
- Watershed Management
- Watershed Management
- Wildlife and Fisheries Management
- Mining and Minerals Management

Resource Protection Activities

- Fire Suppression and Fuels Management
- Emergency Rehabilitation of Watershed Following Wildfire

Resource Access and Facilities

- Access and Transportation Systems and Facilities.

Each of these have subcategories and each sub-practice is explained using the following outline.

Practices

- Includes the number of the practices and a brief title.

Objectives

- Describes the desired results or attainment of the practice as it relates to water quality protection.

Explanation

- Further defines the brief title and expresses how the practice is applied. Describes criteria or standards used when applicable.

Implementation

- Describes where the practice is applied, shows is responsible for application, direction and supervision, and when the practice is employed.

An example under Resource Management Activities, Range Management would be:

22.14 - Determining Grazing Capability of Lands

1. Objective.
   - To maintain or improve soil stability, soil productivity, and water quality by grazing the land within its capability.
2. Explanation.
   - This practice is an administrative and preventive control. Soil condition classes, based on the relationship of current and natural soil loss tolerances, are used to determine grazing capability. Only land with soils in stable condition are considered as "full capability" range. Grazing capability ratings are then used in conjunction with other grazing considerations to determine the actual grazing capacity of an area.
3. Implementation.
   - Soil condition class is determined by qualified soil scientists using Terrestrial Ecosystem Survey (TES). A range conservationist will use the soil condition class in determining the grazing capacity.To augment the SWCPH and help the project manager develop more site specific practices the Watershed and Air Group in the Southwestern Region develops guidelines like the "Watershed Management Practices for Piñon-Juniper Ecosystems." This document discusses the classification of Woodland Ecosystems, specifically the Piñon-Juniper Woodland, the use of classification for predicting watershed response, determining the desired future condition, current soil and watershed conditions on National Forest System lands, possible management practices that can be used in the piñon-juniper woodland, watershed treatment sequences, and wildlife coordination in woodland projects. The section on Possible Management Practices discusses the following practices:

- Bulldozing, Pushing
- Cabling
- Chaining, Chaining and Windrowing
- Channel Stabilization
- Chemical Treatments
- Grazing Management
- Hand Methods (Cutting, Chopping, Grubbing)
- Infiltration Enhancement Treatments
- Prescribed Fire
- Seeding
- Silviculture
- Slash Treatment
- Soil Amendments
- Tree Crushing/Roller Drum Chopping

Each of these are defined, the research findings are reviewed, and recommendations are made for their use.

Both the SWCPH and the "Watershed Management Practices for Piñon-Juniper Ecosystems" are dynamic and will be added to as new and better techniques are developed. The SWCPH is part of the Forest Service's directive system and can be update at anytime. As new research comes forward or old research is found on the practice being used in the Piñon-Juniper Ecosystem the Watershed and Air Group will incorporate it into the "Watershed Management Practices for the Piñon-Juniper Ecosystem."

By using the Soil and Water Conservation Practices Handbook and accompanying document like the "Watershed Management Practices for the Piñon-Juniper Ecosystems" the Forest Service and others will be able to protect and enhance the soil productivity and assure quality water for down stream uses.

Forest Stewardship & Stewardship Incentive Program (SIP)

Lorie Stoller[1]

BACKGROUND

The purpose of the Forest Stewardship Program is to assist private forest landowners to more actively manage their forest and related resources; to keep these lands in a productive and healthy condition for present and future owners; and to increase the economic and environmental benefits of these lands.

In its initial phase, the goal of the Forest Stewardship Program is to: Place 25 million nonindustrial private forestland (NIPF) acres under forest stewardship management within five years.

For purposes of this program, NIFP acreage includes lands owned by any private individual, group, association, corporation, Indian tribe, or other private legal entity, such as Alaska Native Corporations. Further, it includes rural lands with existing tree cover, or suitable for growing trees.

The Forest Stewardship Program focuses on providing services to landowners not currently managing their forestland according to a resource management plan that embodies multi-resource stewardship principles. Private nonindustrial forestlands that are managed under existing Federal, state, or private sector financial and technical assistance programs may be eligible for assistance under the program if the landowner agrees to comply with the requirements of the program or if forest resource management activities on such forestlands are expanded or enhanced to meet the requirements of the Forest Stewardship Program.

STATE STEWARDSHIP COORDINATING COMMITTEE

To implement the program in New Mexico, the State Forester has been required to establish a State Stewardship Coordinating Committee. The committee is administered by the State Forester and is comprised of individuals representing the following:

- The Forest Service, Soil Conservation Service, Agricultural Stabilization Service, and Extension Service.
- Local Government.
- Soil and water conservation districts.
- Consulting foresters.
- Environmental organizations.
- Forest products industry.
- Forest landowners.
- Land-trust organizations.
- Conservation organizations.
- State fish and wildlife agency.
- Any other appropriate interests.

The Committee is ongoing to address stewardship planning and implementation concerns and overall program coordination.

NEW MEXICO FOREST STEWARDSHIP PLAN

New Mexico is also required to have a Statewide Forest Stewardship Plan which serves as the dynamic framework for program implementation. The Plan is action oriented, multi-disciplinary in scope, and concurred in by a majority of the State Stewardship Coordinating Committee in writing. The Plan identifies partnership between the interagencies and organizations and covers the five year period between 1990 to 1995. The Plan also sets the priorities for achieving the goal and objectives identified for the State for each Fiscal Year through 1995.

LANDOWNER REQUIREMENTS

The landowner must own a minimum of 10 NIPF acres. There is no maximum. Eligible rural landowners must agree to abide by a written Forest Stewardship Plan that is developed, for a 10 year lifespan, by a resource professional for the land. The landowner's plan must identify and describe the actions that will be taken to protect, manage, and improve the forest resource consistent with the landowner's objectives. The landowner must sign a pledge of intent to abide by the multiresource management.

[1] *Stewardship Coordinator, New Mexico State Forestry, Chama, NM.*

LANDOWNER PLAN REQUIREMENTS

Landowner plans may only be developed by State Forestry, the Soil Conservation Service, or by private forestry consultants. The following resource values are to be addressed: Fish and Wildlife Habitat Enhancement, Threatened and Endangered Species, Soil and Water, Wetlands, Recreation and Aesthetics, Forest Management and Timber Harvesting.

The above information pertains to the Forest Stewardship Program. In order to encourage private landowners to follow the above program, a cost share incentive program has been developed. This program is called the Stewardship Incentive Program (SIP).

STEWARDSHIP INCENTIVES PROGRAM (SIP)

BACKGROUND

The purpose of the Stewardship Incentive Program is to encourage private landowners to manage their forest lands for economic, environmental, and social benefits; complement and expand upon existing forestry and conservation assistance programs; and to give priority to tree planting, tree maintenance, and tree improvement.

A landowner shall own a minimum of 10 but not more than 1,000 NIPF acres in New Mexico. The landowner must agree to manage lands under a Forest Stewardship Plan and to maintain stewardship practices for 10 years.

Landowners interested in cost share under SIP apply at the local ASCS office. A paperwork shuffle occurs between agencies, and in the end, the ASCS will arrange for reimbursement payments to be made to the landowners. The entire application procedure for SIP is very similar to the other cost share programs--especially ACP.

WHAT'S AVAILABLE TO COST SHARE

New Mexico is offering all nine stewardship practices, which are

- SIP--1: Landowner Forest Stewardship Plan Development
- SIP--2: Reforestation and Afforestation
- SIP--3: Forest and Agroforest Improvement
- SIP--4: Windbreak & Hedgerow Establishment and Maintenance
- SIP--5: Soil & Water Protection & Improvement
- SIP--6: Riparian & Wetland Protection & Improvement
- SIP--7: Fisheries Habitat Improvement
- SIP--8: Wildlife Habitat Improvement
- SIP--9: Forest Recreation Enhancement

New Mexico will cost share SIP 1 at 75%, while all other practices will be cost shared at a 65% rate. The maximum reimbursement is $10,000 per landowner per Federal Fiscal Year.

PROGRESS REPORT

Thus far, New Mexico's landowners have been very enthusiastic about this cost share program. In fact, out of the $207,200 allocated to the state for Fiscal Year 1993, there are approximately only $6,000 in funds remaining. A priority system has been developed to determine which applications will receive these remaining funds. The order of priorities will be SIP 1, 2, 3, 6, 8, 4, 7, 5, and SIP 9.

New Mexico has approved approximately the following funds/practice:

- SIP 1--2,000 or 1% of total funds
- SIP 2--7,000 or 4% of total funds
- SIP 3--13,500 or 7% of total funds
- SIP 4--157,000 or 83% of total funds
- SIP 5--0 or 0% of total funds
- SIP 6--0 or 0% of total funds
- SIP 7--4,000 or 2% of total funds
- SIP 8--7,000 or 4% of total funds
- SIP 9--0 or 0% of total funds

Information on the state's SIP funding for Fiscal Year 1994 will not be received until December 1993 or January 1994. However, future funding is based on accomplishments. We have done well.

For further information regarding Forest Stewardship and the Stewardship Incentive Program (SIP) please contact Lorie Stoller, Stewardship Coordinator, New Mexico State Forestry, Rt. 1, Box 100, Chama, NM, 87520, or call (505) 588-7831. Thank you.

U.S. Market for Imported Pignoli Nuts

Steven Delco, Roberta Beyer, and Fritz Allen[1]

Based on import statistics from the U.S. Department of Agriculture and the U.S. Department of Commerce, U.S. shelled Pignoli nut imports have declined since 1989 from 4,019,156 pounds in 1989 to 2,596,928 pounds in 1992 (fig. 1). However, in that same time period the dollar value of those shelled imports rose from $8.8 million in 1989 to $12.2 million in 1992 (fig. 2). This dollar increase resulted from a more than doubling of the average imported price of shelled Pignoli nuts. The nuts rose from $2.19/pound in 1989 to $4.69/pound in 1992 (fig. 3).

The major suppliers to the U.S. during those years were China, Portugal, Hong Kong, and Spain. China has maintained the dominant position in supplying Pignoli nuts to the U.S. market. China's Pignoli nut price has more than doubled from $2.02 in 1989 to $4.60 in 1992 (table 3). In comparison to China and Hong Kong, Spain, Portugal, Turkey and all the other suppliers have been minor competitors in this U.S. Pignoli nut market. There are regional varieties of the pine nut throughout the world. For example the Spanish and Italian pine nut is a different variety from the Chinese nut. Importers of the Spanish or Italian nuts may be willing to pay more for it because they have a specialized market for that variety.

Consistently the Spanish, and Italian Pignoli have been double the price of the Chinese and Hong Kong nuts. Other countries that supplied the U.S. with Pignoli nuts between 1989 and 1992 include, Lebanon, Mexico, Pakistan, Switzerland, U.K., Taiwan, and Japan. However, seen from tables presented below their contribution was minor (table 1).

As the labor for picking and shelling these nuts has increased throughout the world, especially in China, the price for these U.S. imports has been driven up.

There are no records, we have uncovered that account for the total consumption of pine nuts in the U.S. Therefore, we have no way of knowing what percentage of the total U.S. consumption, imports represent. Based on discussions with regional suppliers in the U.S. southwest, it was estimated that as much as 7 million pounds of pinon (pine nuts) were harvested in 1991-1992. It is difficult to know exactly how much of the southwestern varieties are sold. Much of what is picked is used by the Indians that collect them. There is evidence that much goes to waste.

Based on the current price of the pine nuts imported into the U.S. in 1992 at an average world shelled price of $4.65/pound (table 3) the southwestern piñon nut, which seems to range in price, unshelled between $1.5 to $3/pound, could become competitive, especially if automation is developed for shelling the nut.

We believe that there may be a real window of opportunity to market the piñon nut throughout the U.S. at this time. An understanding of the marketplace and the potential for developing a economic and environmental policy for growing, harvesting, shelling, and marketing piñon nuts is key to competing in the U.S. and world market with these nuts. The pinon nut lends itself to a variety of products.

Our team has explored several methods of automating the shelling of the piñon nut. We believe that with the proper financing an automated shelling device could be developed and could bring the New Mexican shelled piñon nut in line with the current world price for shelled pignoli nuts. In addition to selling the raw nuts, there are a number of value added products that could be developed. The value added products would be less price sensitive and sales based much more on "Image" marketing.

Piñon nuts were successfully marketed in the U.S. market in the 1930's and 1940's. They were marketed in vending machines all over the east coast and were called "Indian Nuts". We believe that there is an opportunity to bring back that kind of market for the nut as raw unshelled, shelled or as an ingredient in a number of quality products i.e., gourmet ice cream, dressings, sauces, cookies, etc.

[1] *Albuquerque, New Mexico.*

Table 1

US Pignoli Nut Imports (in Pounds)				
	1989	1990	1991	1992
World Total	**4,019,156**	**2,279,889**	**2,717,158**	**2,596,928**
Portugal	266,850	109,119	900,295	23,819
Turkey	0	5,360	532,039	141,795
Spain	57,743	123,055	480,117	25,587
China	2,829,721	1,710,558	549,647	1,865,569
Hong Kong	696,336	305,164	247,616	492,053
Italy	0	0	6,078	8,771
Lebanon	0	0	1,367	0
Mexico	0	13,293	0	0
Pakistan	0	3,358	0	1,327
Switzerland	100,832	9,983	0	0
UK	29,480	0	0	0
China(Taiwan)	38,193	0	0	0
Japan	0	0	0	38,007

Figure 1

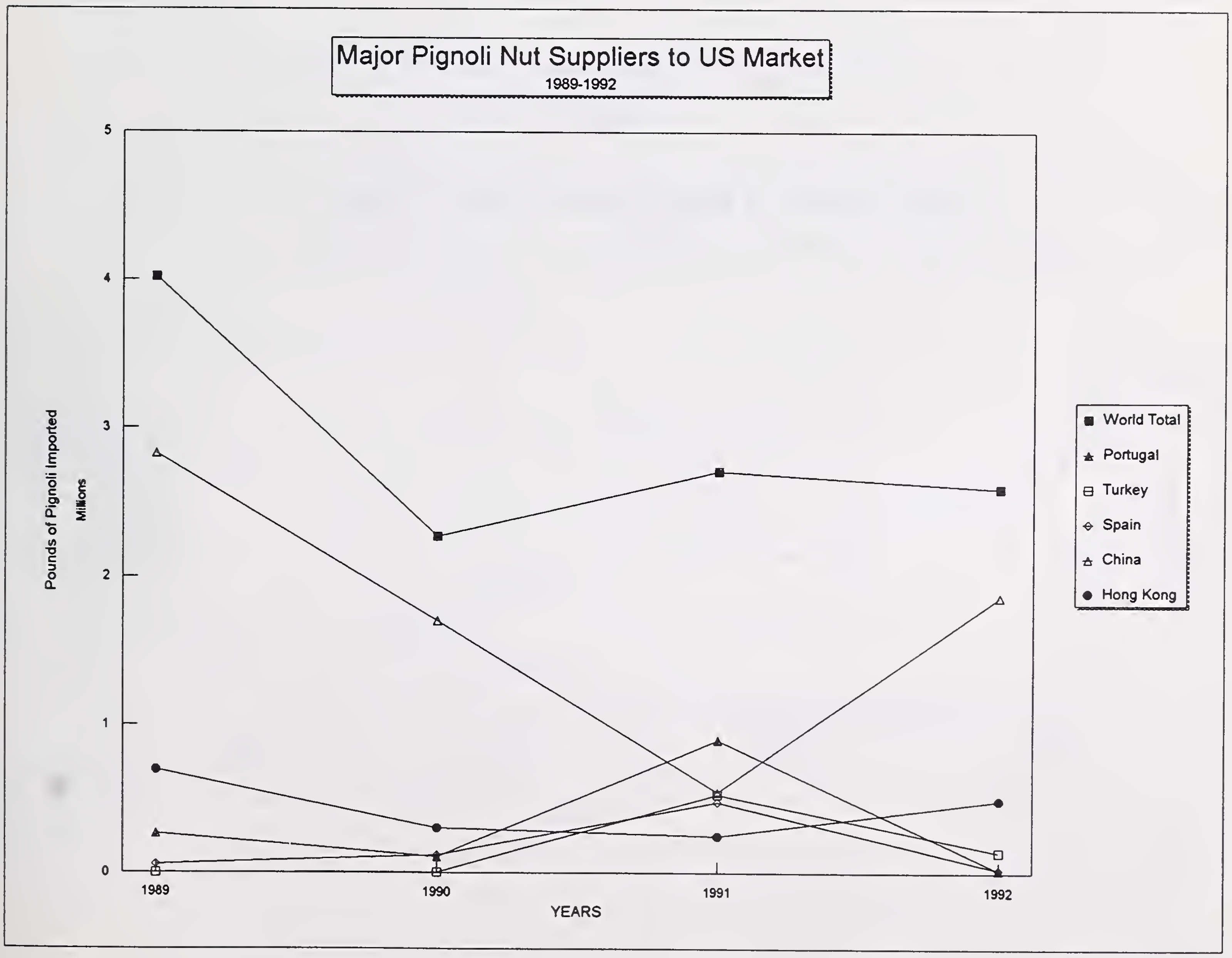


Table 2

Pignoli Nuts US Dollar Imports (CIF) (Shelled) In Thousands				
	1989	1990	1991	1992
World Total	**$8,816**	**$5,810**	**$13,599**	**$12,170**
Portugal	$1,008	$466	$5,103	$121
Spain	$286	$455	$2,387	$230
China	$5,720	$4,074	$2,175	$8,590
Hong Kong	$1,439	$718	$909	$2,138
Italy	$0	$0	$39	$79
Lebanon	$0	$0	$9	$0
Turkey	$0	$29	$2,977	$628
Mexico	$0	$38	$0	$0
Pakistan	$0	$6	$0	$7
Switzerland	$219	$25	$0	$0
UK	$71	$0	$0	$0
China(Taiwan)	$72	$0	$0	$0
Japan	$0	$0	$0	$183

Figure 2

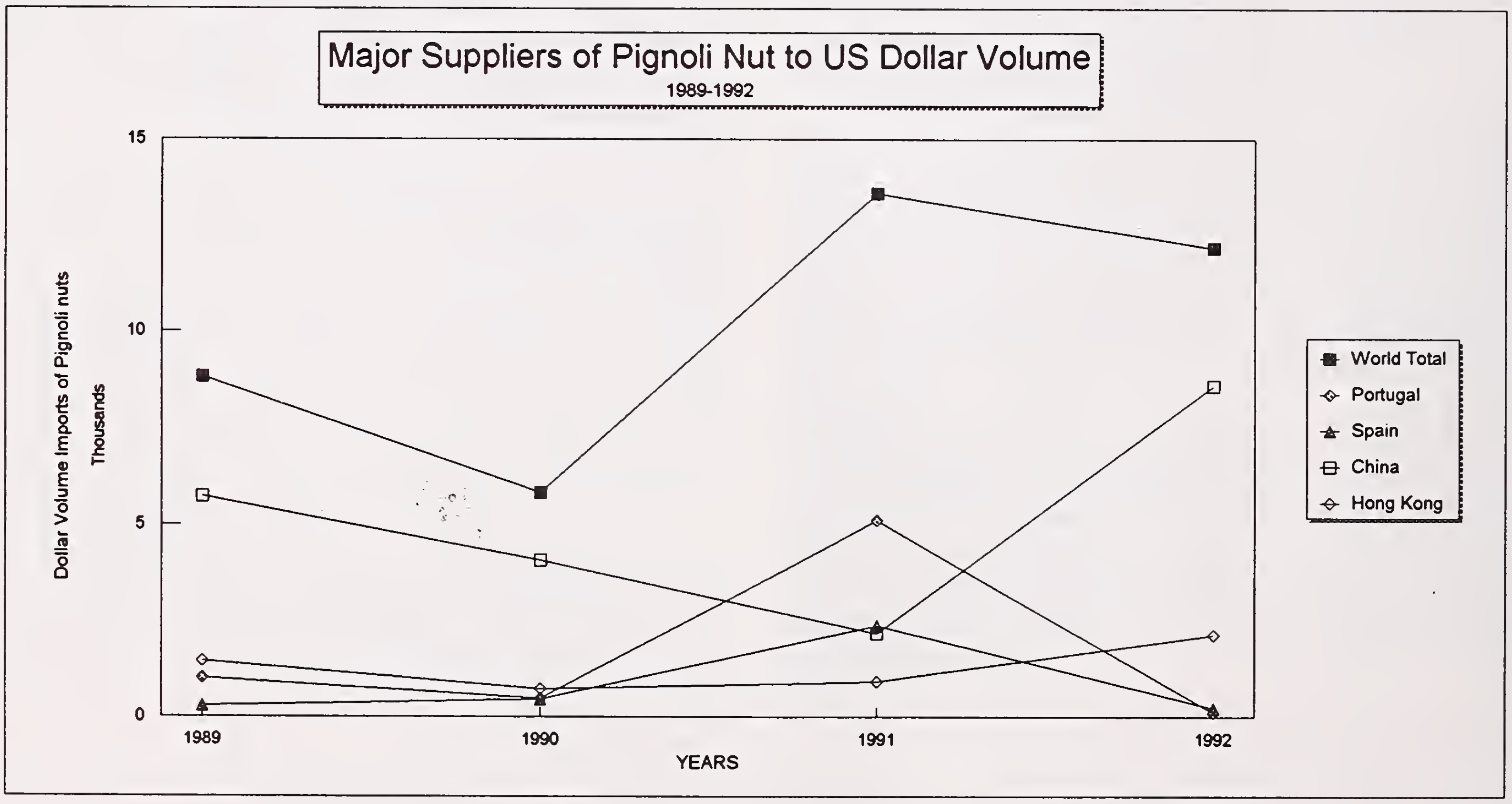
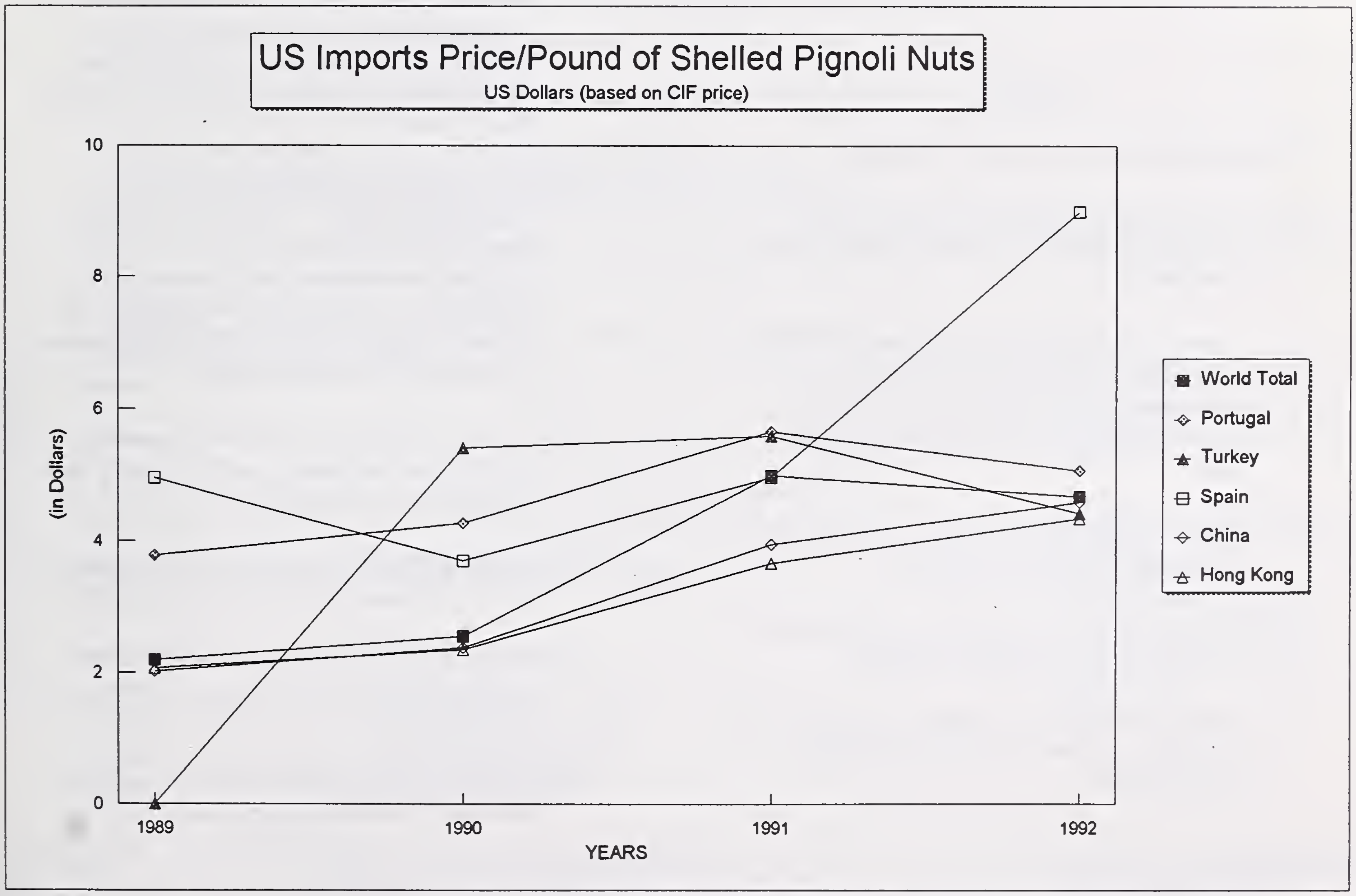


Table 3

US Import Price/Pound of shelled Pignoli (based on CIF price)				
	1989	1990	1991	1992
World Total	**$2.19**	**$2.55**	**$5.00**	**$4.69**
Portugal	$3.78	$4.27	$5.67	$5.08
Turkey	$0.00	$5.41	$5.60	$4.43
Spain	$4.95	$3.70	$4.97	$8.99
China	$2.02	$2.38	$3.96	$4.60
Hong Kong	$2.07	$2.35	$3.67	$4.35
Italy			$6.42	$9.01
Lebanon			$6.58	
Mexico		$2.86		
Pakistan		$1.79		$5.27
Switzerland	$2.17	$2.50		
UK	$2.41			
China(Taiwan)	$1.89			
Japan				$4.81

Figure 3



Action Plan Resulting from the Piñon-Juniper Symposium

INTRODUCTION

As a follow-up to this symposium, a group of participants and other interested people met to develop this action plan. The meeting was held on May 6 in the New Mexico State Land Office. The intent of the plan is to identify actions organizations could undertake to improve the management of piñon-juniper ecosystems in New Mexico for ecosystem sustainability and social needs.

GOALS

The individual goals for the action plan are:

(1) Provide for optimum use of the resources available from New Mexico's piñon-juniper ecosystems.

(2) Provide for sustainable use of the ecosystem while maximizing biological diversity, maintaining or improving soil productivity and water quality, and protecting cultural needs.

(3) Balance management and use to sustain the system and meet human needs.

(4) Optimize use while protecting resources with an emphasis on watershed condition.

(5) Harvest as much of the piñon nut crop as can be utilized without a negative impact on the ecosystem.

(6) Restore to health deteriorating ecosystem conditions in the piñon-juniper.

(7) Develop industry and uses of the piñon-juniper system in an environmentally conscientious way, with a balance of cultural needs.

(8) Be able to describe the existing condition, the potential condition for a sustainable system, and the desired future condition for the piñon-juniper. Also have the management tools needed for moving toward the desired future condition.

(9) An increased understanding of the piñon-juniper from a historical, biological, and cultural standpoint to allow for the development of sustainable management practices for piñon-juniper woodlands. An understanding of how we got to the current conditions in the piñon-juniper.

(10) A way to express the value of resources, such as soil and water quality is being lost due to lack of management.

(11) Better public understanding of the value of the resources associated with piñon-juniper.

(12) Better management understanding of the value of the resources associated with piñon-juniper.

(13) A better understanding of why some areas are more productive than others.

ACTION PLAN

RECOMMENDED ACTION	ACTION GROUP/AGENCY
(1) Initiate research to increase our knowledge of energy flows in the piñon-juniper ecosystems. ***Research Topics*** (a) Needs and roles of piñon jays and other seed eating birds? (b) Needs and roles of small mammals? (c) Needs and roles of soil biology? (d) Needs and roles of cryptogamic crusts? (e) The importance of dead and down material in nutrient cycling? (f) Is there a symbiotic mycorrhizal relationship in piñon-juniper woodlands? (g) Frequency and role of fire in different piñon-juniper habitat types? (h) Factors that affect seed production and reproduction, including competition? (i) Roles in the hydrologic cycle, especially ground water? (j) The impacts of higher nut removal efforts on energy flows and material cycles? (k) What are the energy and material flow relationships with higher and lower ecosystem scales? (l) The effects of herbivore use on nutrient cycling? (m) Roles of piñon-juniper trees in the carbon cycle? (n) What are the potential impacts of increased piñon-juniper management and utilization on social and cultural values of traditional communities?	**Forest Service/ Universities**
(2) Initiate additional research to develop more and better ecosystem restoration techniques. ***Research Topics*** (a) Potential for use of organic amendments? (b) Reforestation techniques? (c) Optimum times and prescriptions for using fire to control piñon-juniper in grasslands and woodland tree densities in woodlands? (d) Optimum times and prescriptions for using chemicals to control piñon-juniper in grasslands and tree densities? (e) How will harvesting techniques and restoration methods affect soils, water, vegetation, animals, and cultural resources? (f) Proper thinning, pruning, and other silvicultural prescriptions? (g) Most appropriate grasses and forbs for seeding under trees and in interspaces? (h) Effects of restoration methods on neo-tropical migratory bird populations?	**Forest Service/ Universities**
(3) Develop recommended management practices to move piñon-juniper ecosystems toward several desired future conditions. (a) Include access management. (b) Institute a free use permit that explains how to harvest nuts and proper behavior in the woodlands or woodland etiquette.	**Land Management Agencies**
(4) Implement an Anti-Fuelwood Poaching Campaign.	**Land Management Agencies and Piñon Nut Industry**
(5) Implement an inventory and market analysis for alternative woodland products. (a) Determine system's tolerance for harvesting nuts, wildings, and Christmas trees.	**Universities, Rural Economic Project**
(6) Implement an inventory and market analysis for piñon nut products.	**Universities, Rural Economic Project**
(7) Implement a piñon nut crop forecasting and record service.	**Forest Service**
(8) Develop piñon nut shelling machine.	**Forest Service Equipment Development Center**
(9) Develop piñon nut storage methods.	**Forest Service Tree Seed Laboratory**
(10) Establish a clearing house for piñon-juniper information. (a) Develop spatial and tabular data storage capabilities. (b) Establish a geographic information system coordinator. (c) Include information on all piñon-juniper resources. (d) Include lists of experts. (e) Include lists of references.	**State Forester**
(11) Develop intensive nut production practices for private lands.	**New Mexico State University**
(12) Develop a "green product" line marketing campaign.	**Rural Economic Project**
(13) Establish criteria for bonded warehousing of piñon nuts to facilitate third party financing of crop purchases.	**Agricultural Research Service/Universities**
(14) Publish nutritional analyses of piñon nuts and comparisons with foreign pine nuts.	**Agricultural Research Service/Universities**
(15) Set aside "Piñon Nut Harvest Areas" and actively manage them for piñon nut production.	**Land Management Agencies**